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13. ABSTRACT (Maximum 200 Words)

The Alaska Natural Heritage Program (AKNHP) provided services to map the extent of habitat spawned upon by sockeye salmon (*Onchorynchus nerka*) in Upper and Lower Sixmile Lakes on Elmendorf Air Force Base (EAFB), Alaska, during summer 2001 and 2002. The purpose of the project was to provide baseline inventory information on sockeye spawning habitat which could be used to identify spawning areas for management protection. Project objectives included: locating and georeferencing sockeye salmon spawning areas; developing a Geographic Information System (GIS) database that included maps of spawning habitat and physical lake characteristics, including locations freshwater springs during summer and winter; collecting continuous water temperature data at both spawning and control sites. This two-year study was completed in spring 2003. This report summarizes the methodologies used, project results, and makes recommendations about protection for priority spawning sites.

14. SUBJECT TERMS
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INTRODUCTION

The Alaska Natural Heritage Program (AKNHP) was contracted to provide services to monitor and map the distribution of sockeye salmon (*Oncorhynchus nerka*) spawning habitat in Upper and Lower Sixmile Lakes on Elmendorf Air Force Base (EAFB), Alaska, under Contract Award No. DAMD17-01-2-0012. The purpose of this project was to locate and describe spawning sites in the Sixmile Lake drainage and to provide baseline inventory information on sockeye salmon age structure.

Habitat plays a central role in salmonid conservation. Habitat loss or degradation is the key reason why the majority of species (plants, fishes, and wildlife) are being listed at the state and federal levels in the United States (Endangered Species Acts). Identification of key habitats utilized by spawning salmon could be used by managers to ensure their future protection. By providing information on age-class structure and run timing managers may better assess sport harvest escapement goals and projections. To our knowledge, there has not been a comprehensive fisheries assessment of the Sixmile drainage since 1983 (see Rothe and Lanigan 1983). Here we summarize methodologies employed during this two-year study, present final results, and make recommendations to help guide future management decisions.

OBJECTIVES

In May 2001, AKNHP undertook a two-year project to map the distribution of sockeye spawning habitat in Upper and Lower Sixmile Lakes on Elmendorf Air Force Base, Alaska. The objectives of the project were:

1. Locate and describe sockeye salmon spawning areas for management protection.
2. Develop Geographic Information System (GIS) map layers of spawning habitat, including bathymetry and bottom type coverages.
3. Map locations of freshwater springs during summer and winter.
4. Collect continuous water temperature data at both spawning and control sites.

Upon consultation with Kate Wedermeyer, Base Natural Resource Biologist, 2001, additional objectives that would provide information on run timing and salmon age class, not listed in the original contract, were adopted. Secondary objectives included:

1. Perform age and length samples on adult sockeye salmon.
2. Tag salmon with Peterson Disk tags to gain insight into movements, distribution and timing of spawning.

LOCATION

This study occurred over a two-year period, 2001-2003, on Upper and Lower Sixmile Lakes, Elmendorf Air Force Base, Anchorage, Alaska (Figure 1). The Sixmile Creek Basin, which includes Sixmile Creek, Lower Sixmile Lake, and Upper Sixmile Lake, occupies a valley created by an old channel of the Eagle River. The creek is now flooded for most of it's length by the waters of Upper and Lower Sixmile Lakes, which were created by damming Sixmile Creek in 1951. Much of the old creek channel is still visible

in the lakes (Rothe et al. 1983). Sixmile Creek is approximately 1.5 kilometers long and flows into Cook Inlet. Spawning surveys and mapping occurred only in Upper and Lower Sixmile Lakes and not in the creek. The Sixmile Lake system supports populations of sockeye salmon (*Oncorhynchus nerka*), coho salmon (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*).

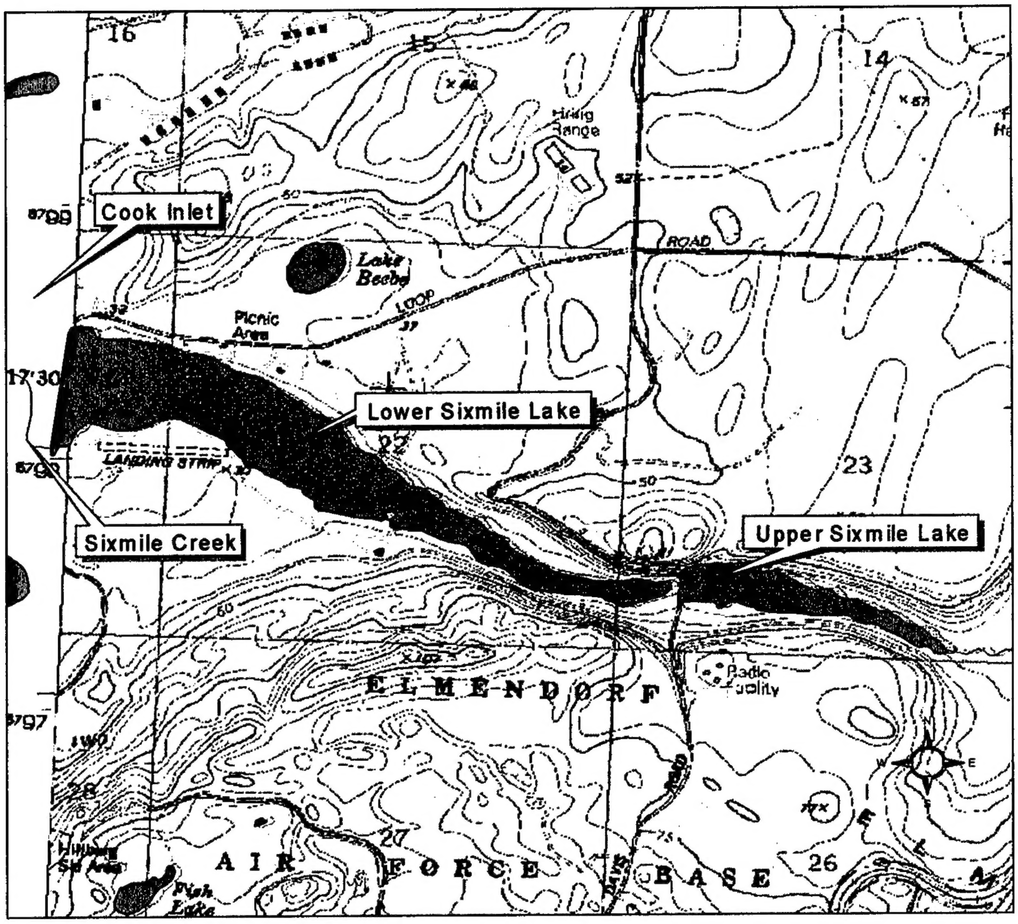

Figure 1. Map of Upper and Lower Sixmile Lakes, Elmendorf Air Force Base, Anchorage, Alaska.

METHODS

Fishery Assessment

Age and Length Sampling and Peterson Disk Tags

To facilitate enumeration and sampling of returning adult salmon, we utilized the existing weir structure located beneath the Sixmile Lake Bridge, adjacent to the fish ladder, to trap and contain fish. Over the duration of the run, a sampling goal of 200 fish, per year, was set to collect information on age, length, and sex ratio. Fish to be sampled were captured using a dipnet once they had been corralled against the weir fence using a beach seine. The sex of each fish was recorded and length was measured to the nearest 1.0 cm (Figure 2). In addition, for each sampled fish we collected a scale sample from the preferred

area. Scale samples were mounted onto numbered and labeled gum cards, pressed onto acetate cards, and aged using a microfiche.

Figure 2. Sockeye salmon sampling for length using fish measuring board.

During 2001, sampled fish were also tagged with a Peterson disk tag. Peterson disk tags are quarter-size flat plastic disks that are attached on both sides of the fish at the base of the front of the dorsal fin using a metal pin. During each sampling period (approximately every 4 to 5 days) a different color tag was used to help assess the length of time adult salmon were present in the lake before spawning occurred. We also wanted to determine whether fish that entered the lakes at different times utilized different spawning areas. Throughout the spawning season, date, location, tag color, and behavior were recorded during spawning assessment surveys (described below).

Spawning Assessment

The distribution of adult sockeye salmon was observed weekly during surveys from a canoe and recorded from the time fish arrived in the lake until spawning was complete. During surveys we noted the general spawning behavior of fishes: prespawning, active spawning, or post spawning. Aggregations of sockeye and observations that fish had cleared away sediment and periphyton from gravel substrate indicated the initiation of spawning. Peak spawning activity was identified as the period when the greatest numbers of sockeye were observed in spawning areas. Dead sockeye along the shoreline and no further evidence of substrate clearing indicated termination of spawning.

Habitat Assessment

Habitat Mapping

Gathering data used to map lake depth and bottom substrate type was performed during summer 2001. Numbered wooden survey stakes were placed at evenly spaced intervals along the perimeter of both lakes and locations were recorded using a GPS. Depth and substrate type information were gathered at approx. 50 m intervals along transects, running in a zigzag direction between survey stake markers. Data on depth were

gathered using depth recording readouts from a fish finder that was attached to the stern of a canoe or motorboat. Depth and location information were converted into geographic coverages and incorporated into an ArcView GIS database.

Whenever possible, bottom-substrate type information was gathered at the same locations as depth data. Substrate analysis was performed by visual or diver observation at each sampling location, depending on depth and water clarity. Bottom substrate type was classified into eight categories, based on the most abundant substrate types observed during a preliminary investigation. These included:

1. small gravel (>8-64 mm)
2. medium to large gravel (>64-128 mm)
3. grass
4. vegetative matt
5. organic layer
6. sand
7. silt
8. undetermined

Whenever possible, aquatic vegetation samples were collected when substrate type was mostly plant material. Plant samples were identified to species by AKNHP Botanists. Substrate type and location information was also converted into geographic coverages and incorporated into an ArcView GIS database.

Water Temperature

Constant water temperature was measured using StowAway Tidbit data loggers at spawning and control sites. Data loggers were buried in bottom substrate and anchored with 2 to 3 lbs. of lead weights. A small buoy and a length of line were attached to each data logger for visual identification and retrieval purposes. Data loggers were launched and set in lakes during fall 2001 and 2002, and retrieved shortly after ice out the following spring. Loggers were programmed to record temperature every five hours. We used *t*-tests to compare mean temperatures recorded between test and control sites, between years, and between lakes.

Freshwater Spring Mapping

Locations where freshwater springs fed into Sixmile Lakes were documented during canoe surveys. Ski surveys were conducted during winter 2002, once the lakes had frozen, to map locations of freshwater springs and openings in the ice which could indicate sites of upwelling groundwater. Locations of both summer and winter springs were incorporated into the GIS database as a separate habitat layer.

Habitat Modeling

Bathymetry and substrate maps were developed in ArcView using a kriging algorithm applied to point data collected for depth and bottom type. Kriging is a geostatisitcal interpolation technique that considers both the distance and the degree of variation between known data points when estimating values in unknown areas. Therefore, a kriged estimate is a weighted linear combination of the known sample values around the

point to be estimated. For bathymetry and substrate layers, an Ordinary kriging model was utilized once semivariograms were accepted. Grids derived from kriged data were added to the GIS database.

RESULTS

Sockeye Salmon Escapement and Total Return

In 2001, the sockeye escapement (weir count) into Sixmile Lakes was greater than 4000 fishes (Figure 3). A total of 4043 fish were enumerated at the weir, but there was also tampering that occurred at the weir (28 July) when an undisclosed number of fish were allowed to enter into the lakes uncounted. Salmon began to enter the lake on 8 July and continued to arrive until 19 August. Peak migration occurred on 24 July when 1188 sockeye were counted through the weir.

A total of 191 sockeye salmon were sampled for age, length and sex ratios during 2001. Four-year old fish dominated the run. The age composition of the escapement consisted of an estimated 62% age 1.2, 23% age 2.2, and 16% age 1.3 based on 71 of 150 samples (79 samples were regenerated or reabsorbed and illegible) (Figure 4). Lengths for all age classes and both sexes combined averaged 50.4 (SE ± 3.15) cm, minimum 40 cm, maximum 61 cm. Females were slightly smaller than males: females averaged 50.2 cm (SE ± 3.46) while males averaged 51.0 cm (SE ± 3.46). The sex ratio of the 191 sockeye sampled was 75% (n = 144) female, 24% (n = 45) male, and 1% (n = 1) unknown. The high incidence of females may have been due to sampling bias. Fish were captured using a dipnet, and females were generally easier to net than males.

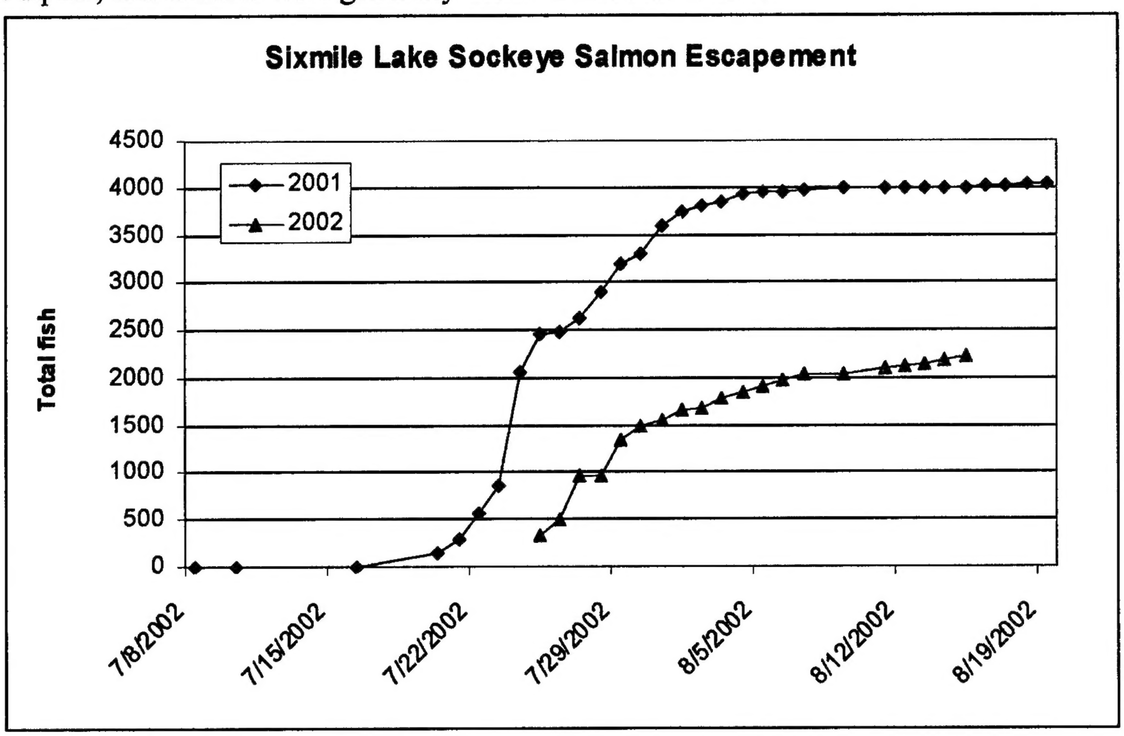

Figure 3. 2001 and 2002 sockeye salmon escapement into Sixmile Lakes, EAFB, Anchorage, Alaska.

The 2002 escapement into Sixmile Lakes was an estimated 2233 fishes (Figure3). Salmon began to enter the lake on 25 July (two weeks later than 2001) and continued to arrive until 15 August. Peak migration counts were recorded on 27 July when 476 fish passed through the weir. However, on 28 July the bottom panel of the weir was found wide open and it is likely that as many as 500 fish passed through uncounted until the breach was discovered and the weir was secured.

A total of 444 sockeye salmon were sampled for age, length and sex ratios during 2002. Five-year old fish dominated the run, although the largest single age class (1.2) was four-year olds. The age composition of the escapement consisted of an estimated 42% age 1.2, 33% age 1.3, 21% age 2.2 (age 1.3 and 2.2 combined = five year olds at 54%). Six-year old (age 2.3) fish composed about 2% of the escapement (Figure 4). Similar to results from 2001, there was a high degree of reabsorbtion in the scales; therefore age class results are based on only 161 of 412 scales taken. Lengths for all age classes combined averaged 50.8(SE ± 2.31) cm, minimum 36.0 cm, and maximum of 68.0 cm. Similar to results reported for 2001, females were slightly smaller than males: females averaged 50.6 cm (SE ± 2.30) while males averaged 51.0 cm (SE ± 5.59). The sex ratio of the 444 sockeye sampled was 70% (n = 313) female and 30% (n = 131) male.

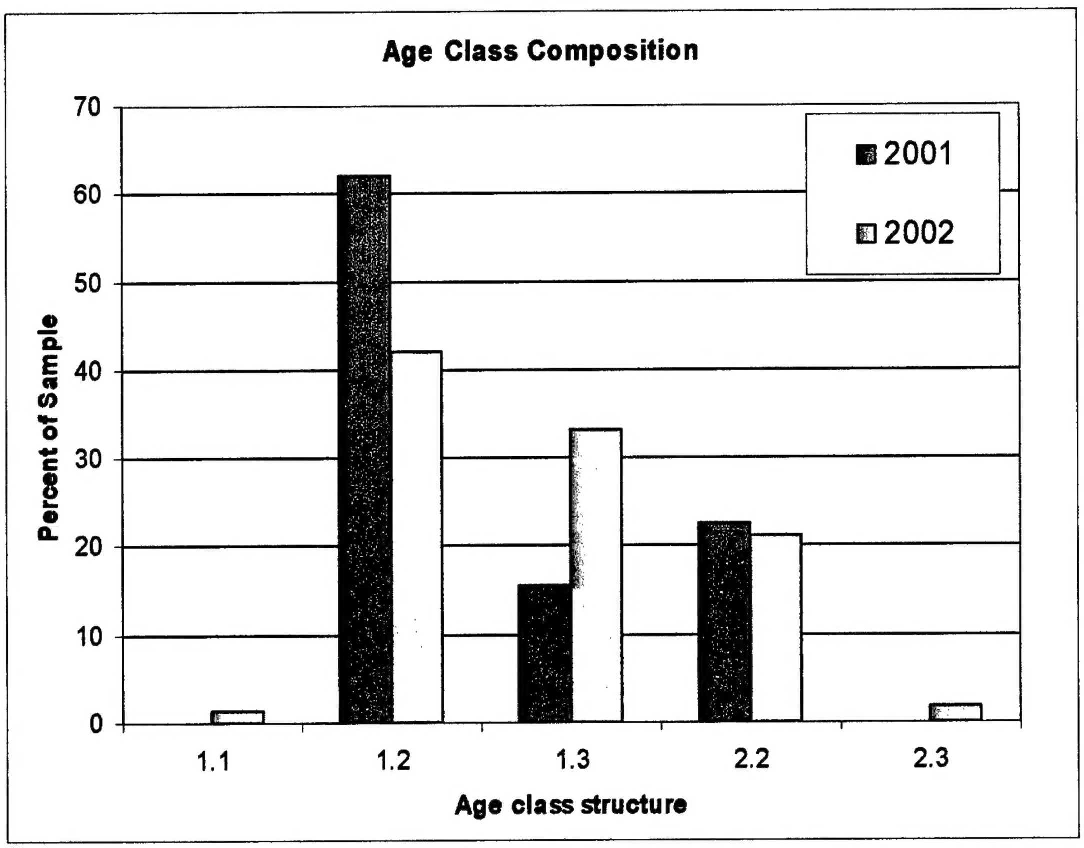

Figure 4. Age class composition for adult sockeye salmon sampled 2001 and 2002 at Sixmile Lake, EAFB, Anchorage.

Peterson Disk Tags

During 2001, a total of 182 fish sampled for length and age were also affixed with Peterson disk tags. The tagging schedule was as follows:

- July 14 – 21 = 30 tags (Pink)
- July 22 – 26 = 54 tags (Green)
- July 27 – 31 = 50 tags (Yellow)
- August 1 – 5 = 46 tags (White)
- August 6 – 10 = 2 tags (Blue)

Total 182 tags

A total of 33 tagged fish were observed during spawning surveys conducted between 20 August and 9 September, 2001. All tagged fish were observed in the Upper Lake and 30 of the 33 were sighted at locations later deemed as spawning areas (although spawning behavior was not always observed in tagged fish). Whether or not tagged observations on different survey dates were duplicate sightings of the same fish is unknown. Tags were not numbered, therefore, it was impossible to identify to the level of individual fishes. Most tagged fish were observed along the south bank of Upper Sixmile Lake at feeder creek outlets, along the roadside/culvert area, and along the northwest bank (Figure 5).

Due to the low number of observations of tagged fish it is difficult to make generalizations about the movements and spawning area preferences of the total population. Of the 33 tagged fish observed in Upper Sixmile Lake, all fish tagged with pink tags (the first fish that entered the system first, July 14-21) were located along the northwest shore. All fish observed with green tags (2nd week of tagging – July 22-26) were observed along the southcentral shore, adjacent to feeder creek outlets. Fish tagged after August 1, with either yellow or white tags, were randomly distributed along both north and south banks and against the roadway (Figure 5).

Due to the September 11th terrorist attack, base security was heightened and the PI for the project was not permitted to return to EAFB until 9 October, 2001. By that time, very few fish remained alive, and spawning was completed. Based on limited spawning observations conducted during 2001, and more intensive surveys conducted during 2002 – it appears that the majority of fish milled around in large schools in deeper water in the middle of the lake(s) until they were nearly ready to spawn. Had we been able to observe fish movements and behavior throughout the duration of the entire 2001 spawning period, it is likely that the results of tagging observations would have been more meaningful (i.e. more tag observations for analysis). Peterson disk tagging was not repeated during the 2002 spawning season.

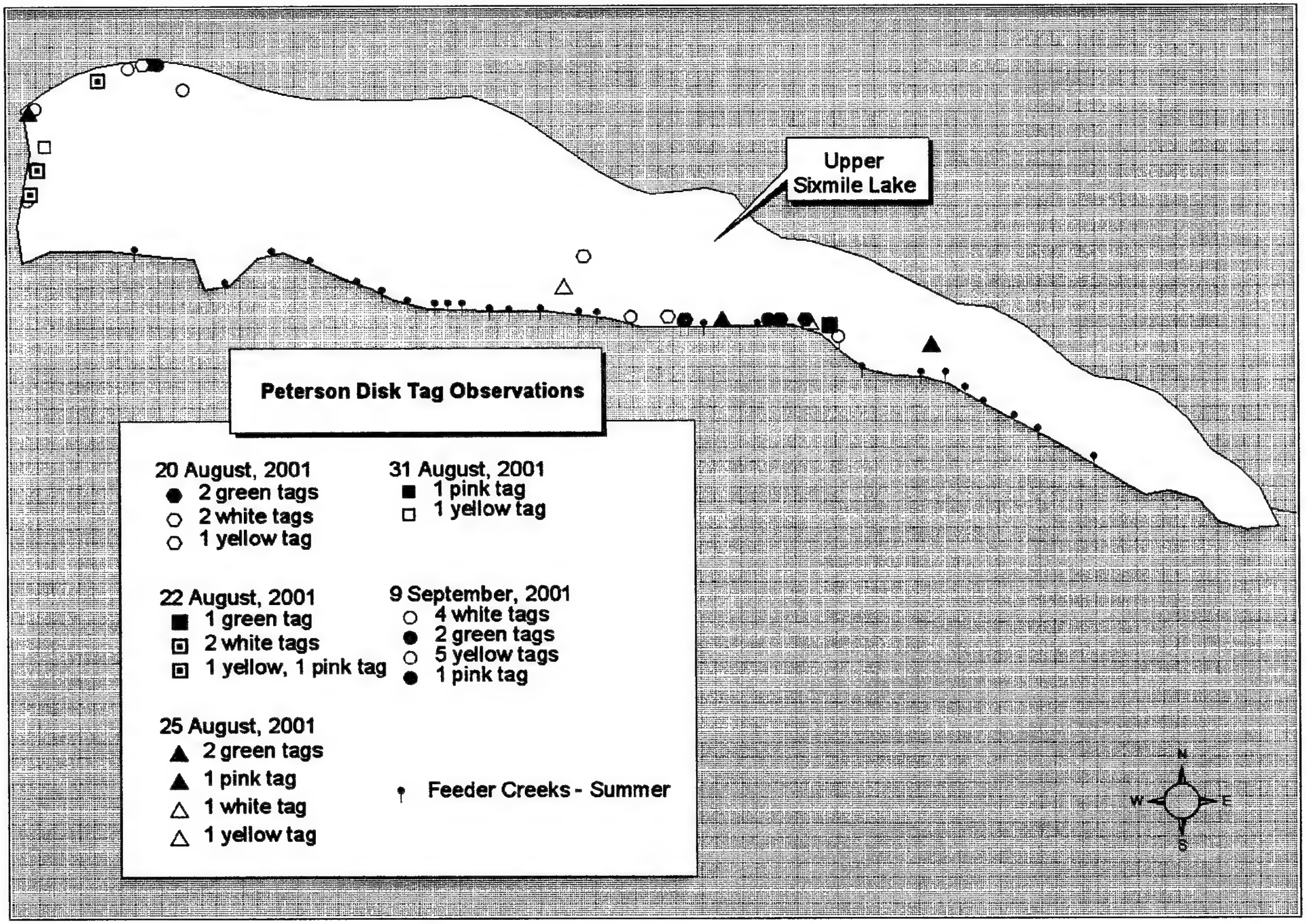

Figure 5. Locations of tagged fish in Upper Sixmile Lake observed during surveys, 8 August to 9 September, 2001.

Spawning Assessment
Spawning observations in Upper and Lower Sixmile Lakes were recorded weekly during 2001 and 2002. During 2001, spawning observations commenced on 20 August and continued through 9 September, were then halted from 11 September to 10 October (reasons described above). Spawning behavior was observed during the 20 August survey, although most fish were simply milling around, establishing territories, and some were digging redds. Peak spawning was observed during the 9 September survey, as the majority of fish observed were actively engaged in spawning and/or defensive behavior. Because we were unable to visit the lake after 11 September, it is highly likely that peak spawning continued for some time after the 9 September observation. The final spawning assessment for the 2001 season was made on 10 October. At that time, very few fish remained alive and spawning was complete. Once eggs are laid in the gravel the female covers them with sediment. Therefore, we were unable to identify spawning areas based on evidence of eggs in gravel once we returned in October for a final spawning assessment.

During the 2002 spawning season, weekly spawning observations commenced 9 August and concluded 9 October, once spawning had ceased and ice was starting to form on the lakes. Similar to results for 2001, spawning behavior was first observed on 20 August. Spawning activity increased on 4 September as fish began to move out of deeper offshore waters and closer to shore to establish territories. Peak spawning activity was observed 9 September to 16 September. Surveys conducted 23 September revealed very little spawning activity, mostly females guarding eggs, and a high number of mortalities were observed. On 9 October spawning was finished, and less than 50 live sockeye were observed in the entire system.

During surveys, each location where fish were observed, particularly as it pertained to spawning, was recorded and behavior was documented. This information was digitized and entered into a GIS database. The GIS database, **6mile_salmon.apr** (ArcView), will be delivered to EAFB Natural Resource Wildlife Biologist, Herman Griese, at the completion of the project. Within the database, a record was created for each spawning observation. Here we summarize the results of all records combined. For in depth, daily observation information, we encourage accessing the GIS database.

During 2001, a total of 102 behavioral observations were recorded at a total of 13 key spawning sites, and a number of minor sites where only three of four fishes were observed spawning. Although fish were sighted in the lower lake, spawning behavior and eggs present in the gravel were only documented in Upper Sixmile Lake. The majority of spawning occurred along a small portion of the northwest shore, along the roadside and culvert at the west end of the lake, and at various locations along the south shore where there is substantial input from cold water feeder creeks (Figure 6).

Throughout summer 2002, a total of 187 spawning observations were recorded at a total of 22 key spawning sites (17 in Upper and 5 in Lower Sixmile Lake). In the upper lake, fish utilized all 13 key spawning areas identified during 2001, plus an additional four key sites. Spawning densities were highest along the northwest shore, where between 1000

and 1500 fish spawned, compared to the south shore where spawning habitat was more patchily distributed and fish densities were much lower (avg. 10-30 fish per site) (Figure 7). Spawning was also observed in Lower Sixmile Lake at a number of locations. These included: the western end of the lake directly across from the weir, in front of the float plane dock, and in two small pockets along the southeastern bank (Figure 8). Spawning densities in these areas ranged from 30 to 100 fishes.

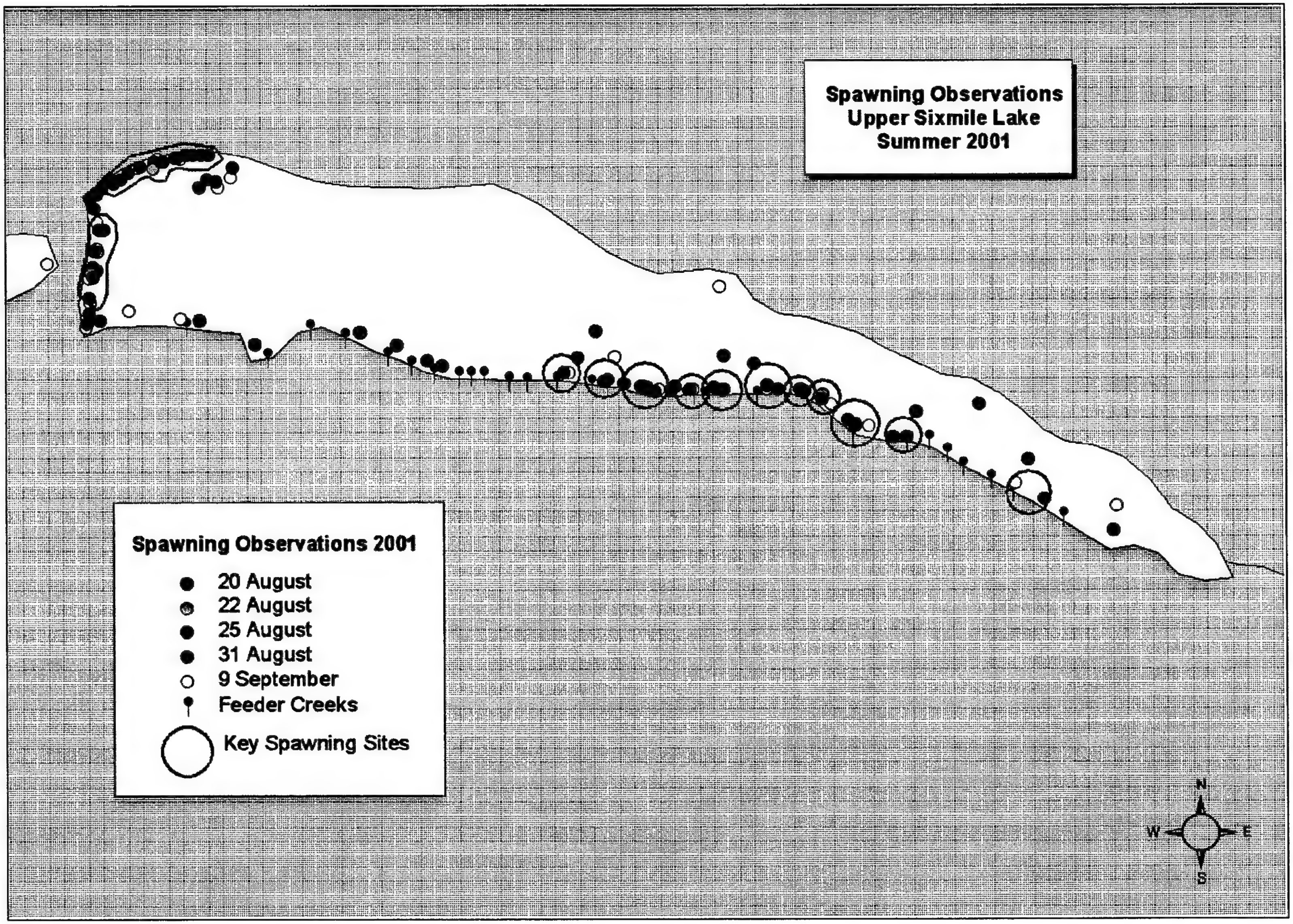

Figure 6. Spawning observations and key spawning sites in Upper Sixmile Lake, 20 August to 9 September, 2001.

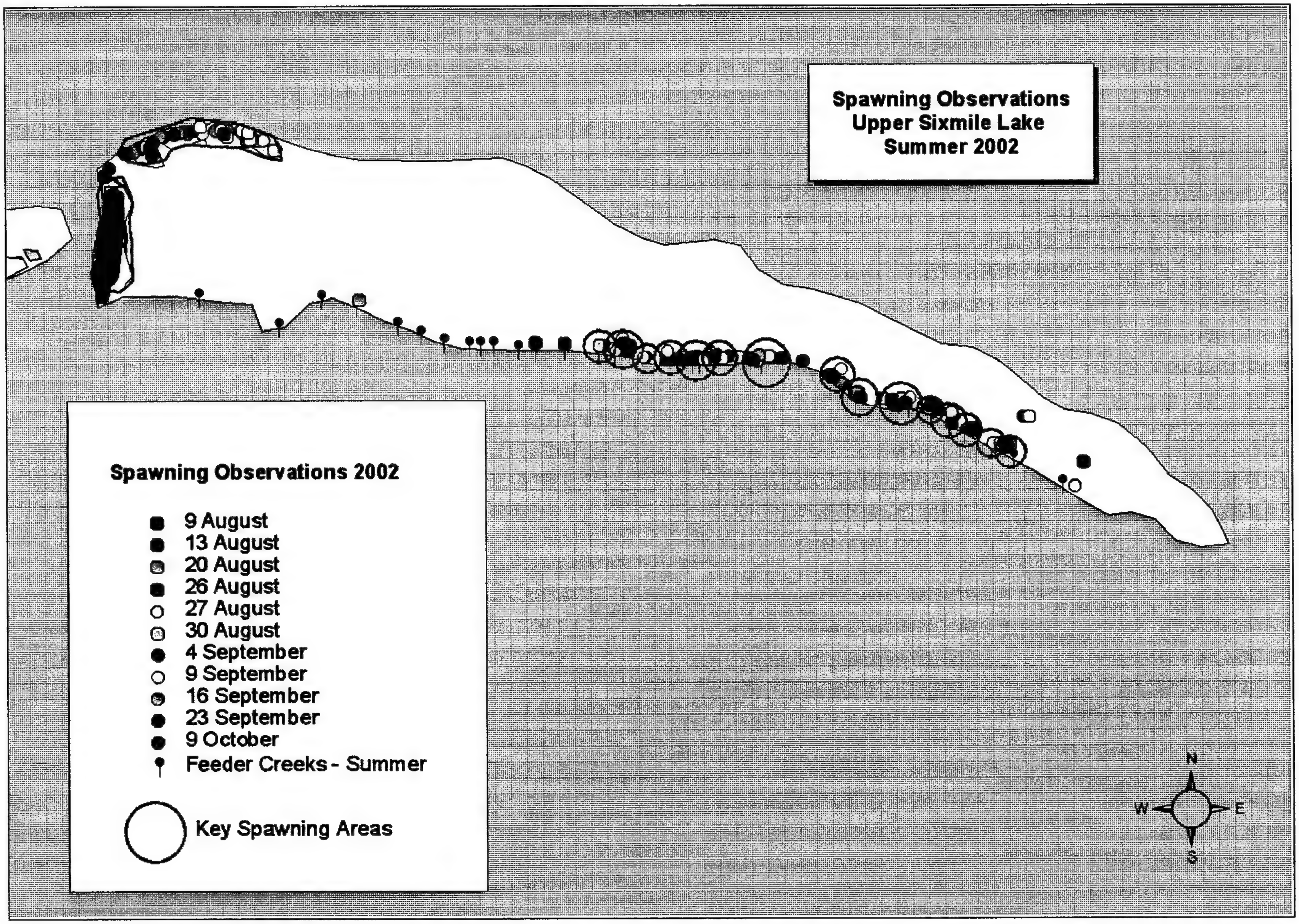

Figure 7. Spawning observations and key spawning sites in Upper Sixmile Lake, 9 August to 9 October, 2002.

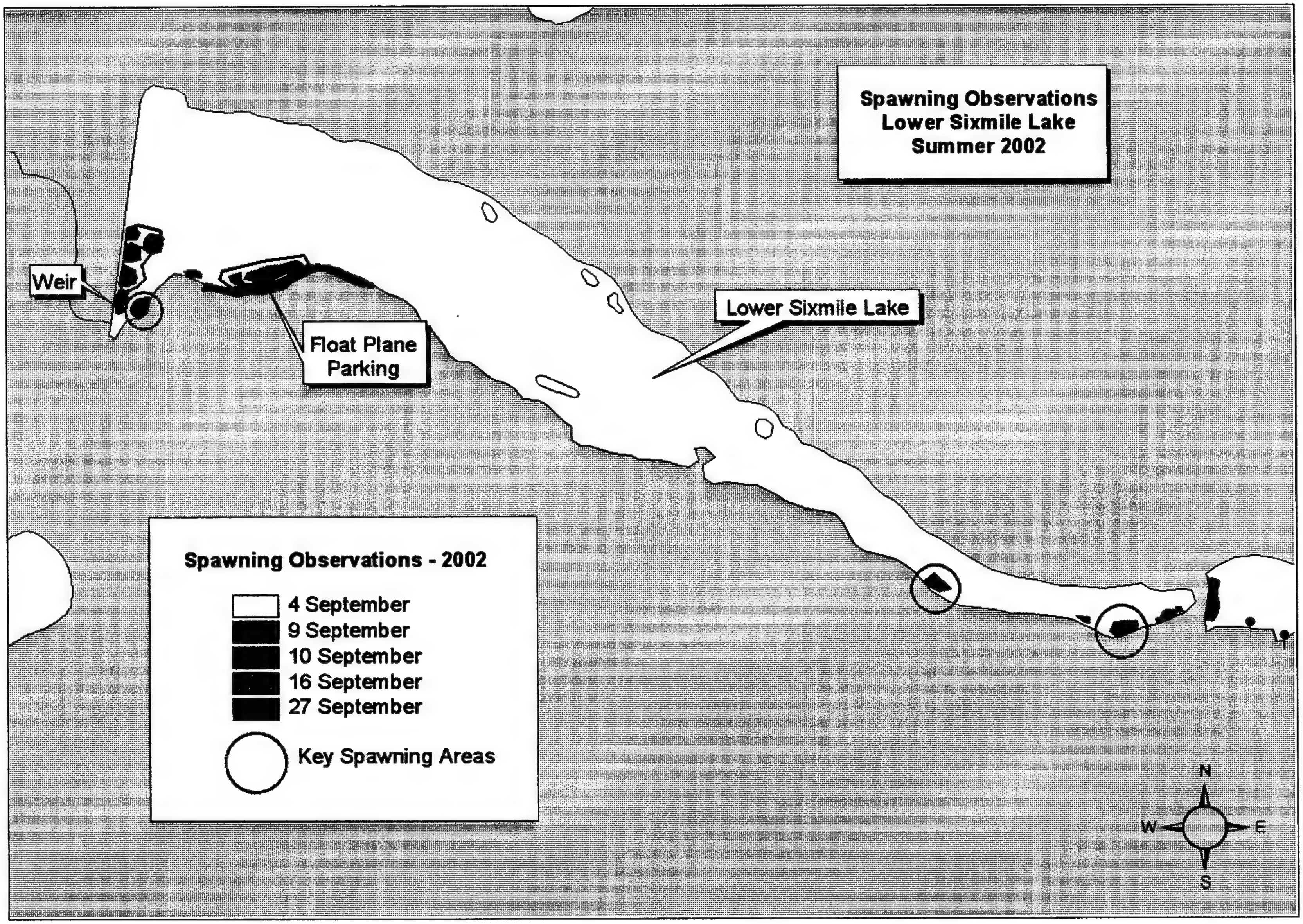

Figure 8. Spawning observations and key spawning sites in Lower Sixmile Lake, 4 September to 27 September, 2002

Characteristics of Spawning Habitat

Most observed spawning occurred within 25 m from shore, in relatively shallow water (less than 2 m, avg. 1 m). Ninety percent of the spawning habitat utilized by sockeye salmon in both Upper and Lower Sixmile Lakes had gravel as the predominant substrate type (Figure 9). Most gravel areas coincided with areas where of upwelling groundwater or areas receiving freshwater runoff from feeder creeks. There were three small spawning sites along the southeastern shore of the upper lake where the bottom substrate was brown, organic material. It is possible that fish were excavating through the detritus to gravel substrate below, but we never saw evidence of this, nor were we able to ascertain that gravel was the underlying bottom-type.

Many nearshore spawning sites also had a high degree of vegetative coverage. In such areas, spawning densities were highest closest to shore, underneath the cutbank or banks overhung with grass and herbaceous plants. Spawning was also observed in holes beneath fallen trees, and in several deep pools.

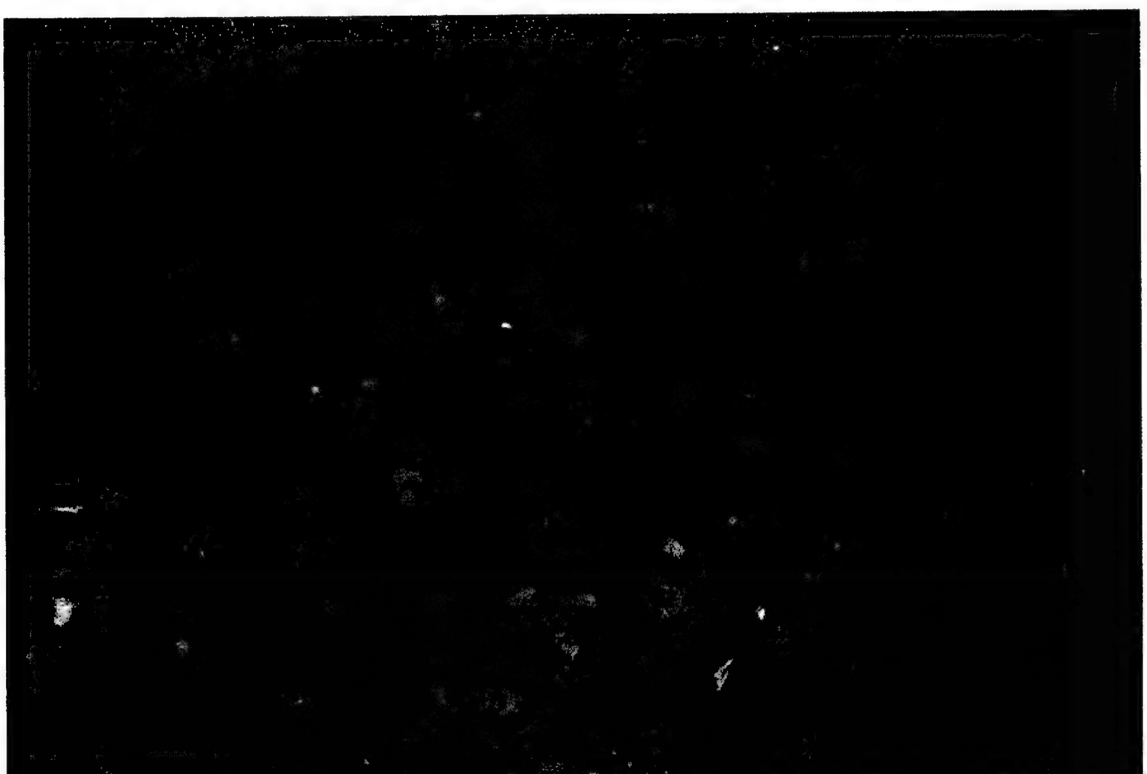

Figure 9. Preferred spawning substrate used by sockeye salmon in Upper Sixmile Lake, EAFB.

Habitat Mapping

Maps of bathymetry and bottom type were developed using an Ordinary Kriging algorithm and incorporated into the GIS database. Once the bathymetry layer was developed, it was used to calculate morphometric characteristics of both lakes (Figure 10). Summary morphological characteristics for Upper and Lower Sixmile Lakes are presented in Table 1.

Table 1. Morphological characteristics of Upper and Lower Sixmile Lakes, EAFB, 2001-2002.

Morphological Characteristics	Upper Sixmile	Lower Sixmile
Surface area (Hectares)	10.39	48.99
Length (km)	1.31	2.32
Perimeter (km)	2.21	6.32
Maximum depth (m)	2.74	5.48
Mean depth (m)	1.07	1.92
Volume (m3)	174,437.54	966,569.96

A map of modeled bottom substrate types is presented in Figure 11. In both lakes, gravel substrate (equated here to primary spawning habitat) was found patchily distributed along lake shores, and gravel patches seldom extended > 100 m from shore. A sand/silt bottom predominated the deeper, middle sections of both lakes. The eastern half of Lower Sixmile Lake becomes quite shallow, and the bottom is completely covered with a dense aquatic vegetative matt primarily composed of mares tail (*Hippuris* spp.) and pond weed (*Potamogeton* spp.). This vegetative matt continues around much of the perimeter of Upper Sixmile Lake, except for areas where gravel predominates.

Freshwater Springs

A total of 30 freshwater feeder creek/spring outlets were mapped during summer surveys conducted in 2001 and 2002. These freshwater springs are essentially out-pourings of ground water or subterranean flows occurring along the shore of the lakes. Twenty-eight were in the upper lake, two in the lower lake. During winter, 26 springs (identified by open water at inflow) were mapped – 25 in the upper lake and one in the lower lake. At least twenty of the springs identified during winter were derived from feeder creeks previously mapped in summer (Figure12). All feeder creeks/springs were located along the southern bank of the lakes. Approximately 19 of the feeder creek outlet sites were used as spawning areas by sockeye salmon.

Water Temperature

Eleven temperature data loggers were deployed during the summer 2001 field season (Figure 13). Two control data loggers were placed in each lake at randomly selected locations. The remaining seven were placed at salmon spawning locations in the upper lake. Loggers were retrieved on 18 and 21 June, 2002. Of the 11 data loggers, two were lost, for a total of nine loggers for analysis. The mean water temperature for the three control sites in 2001 was 6.73 (SE ± .10), and for the six spawning sites was 3.71 (SE ±.20). Mean water temperatures at spawning sites were significantly colder (P<.0001) than control sites during 2001.

Eighteen loggers were deployed in Upper and Lower Sixmile Lakes during fall 2002 (Figure 14). Eleven of the 18 were placed in the upper lake (9 at spawning sites, 2 at control sites), and seven

were positioned in the lower lake (3 at spawning sites, 4 at control sites). Data loggers were retrieved on 8 May and 6 June, 2003. Of the 18 loggers placed in lakes, 16 were retrieved (two were lost), of which two malfunctioned, leaving a total of 14 loggers for data analysis. The mean water temperature for four control sites was 4.84 (SE ± .35), and for the ten spawning sites was 3.76(SE ± .21). Differences in average water temperature between control and spawning sites were not significant ($P = 0.023$).

When temperature data for 2001 and 2002 were combined, mean water temperature at seven control sites was 5.67 (SE ± .43) and 3.74 (SE ± .14) for 16 spawning sites. Differences in average water temperature between all control and spawning sites combined were significant ($P < 0.002$). Temperature differences were not significant between years ($P = .13$) or between lakes ($P = .25$). Water temperature data derived from data loggers is summarized in Tables 2 (2001) and 3 (2002). Data from each logger was also plotted and graphed. Temperature graphs are presented in Appendix I.

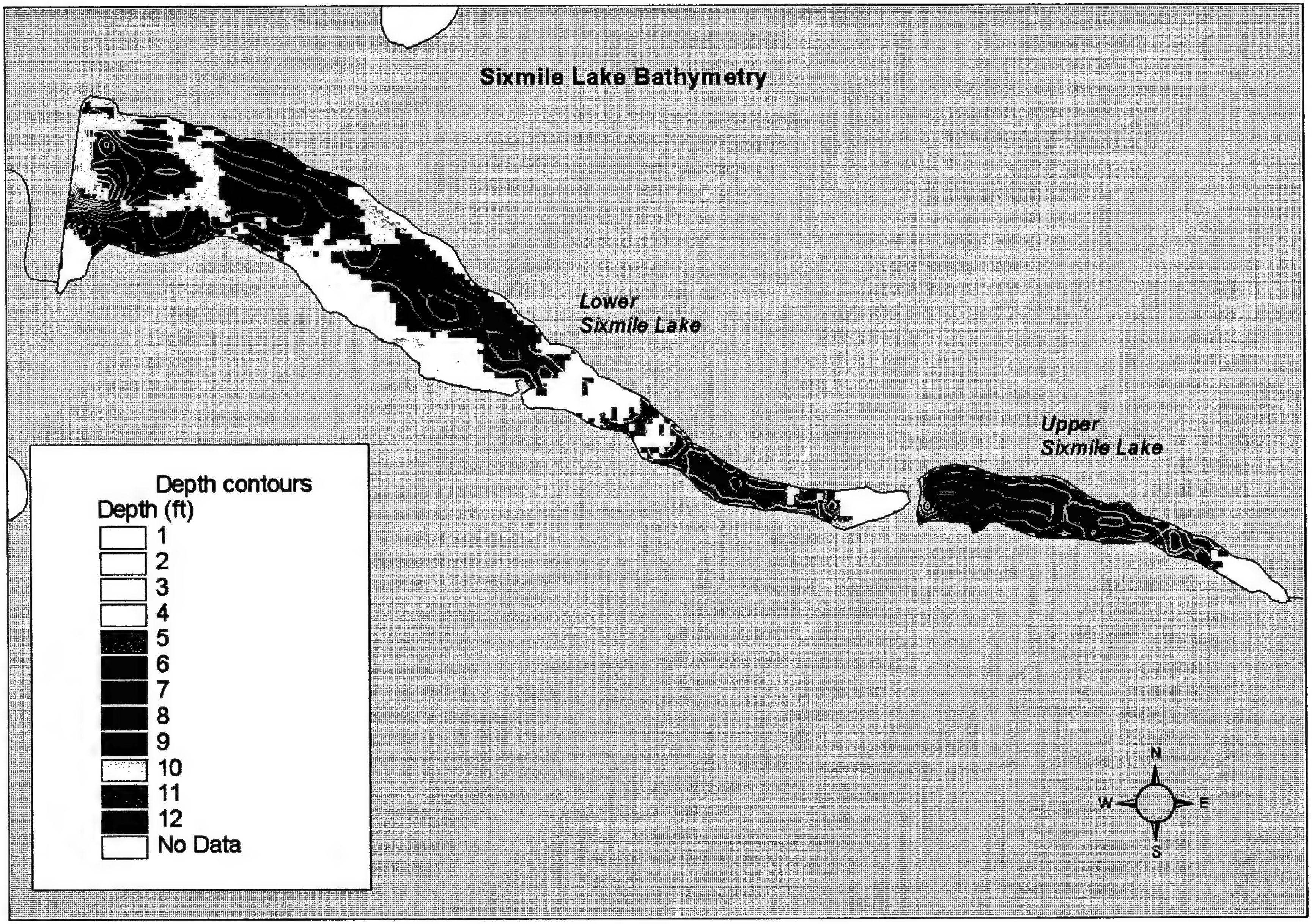

Figure 10. Water depth (in feet) for Upper and Lower Sixmile Lakes, Elmendorf AFB, 2001.

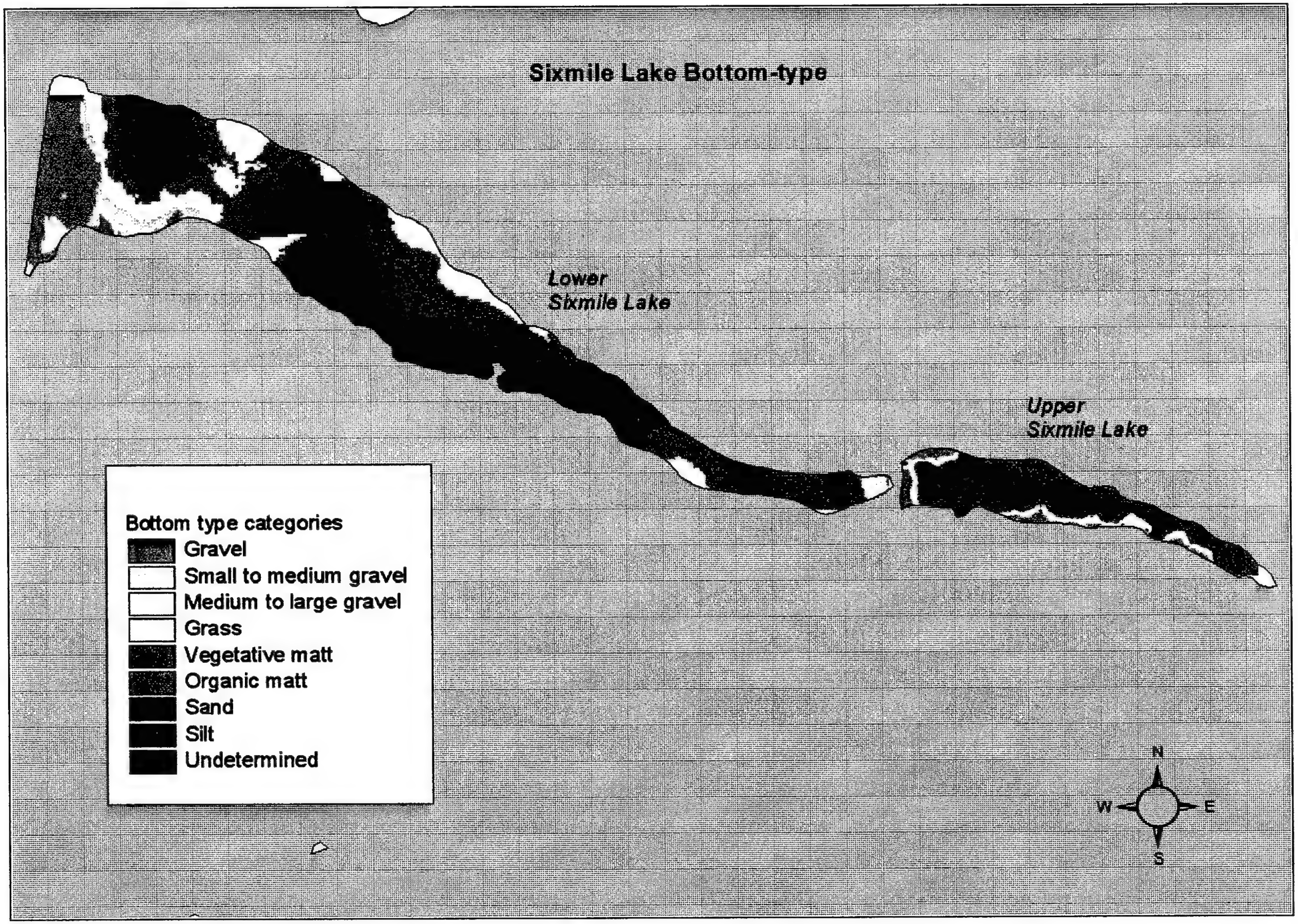

Figure 11. Bottom substrate map for Upper and Lower Sixmile Lakes, Elmendorf AFB, 2001.

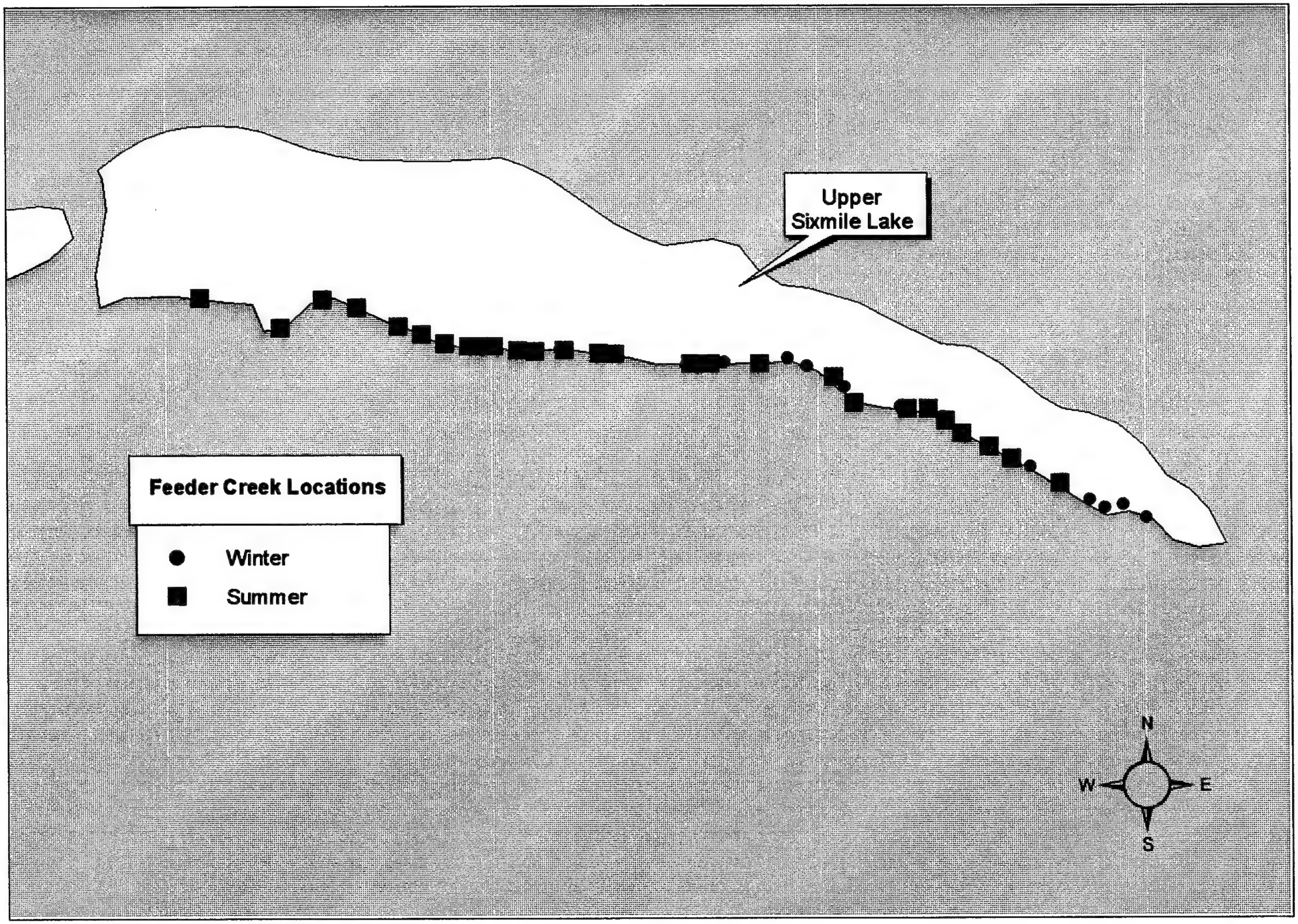

Figure 12. Feeder creek locations during summer and winter on Upper Sixmile Lake, Elmendorf AFB, 2001 and 2002.

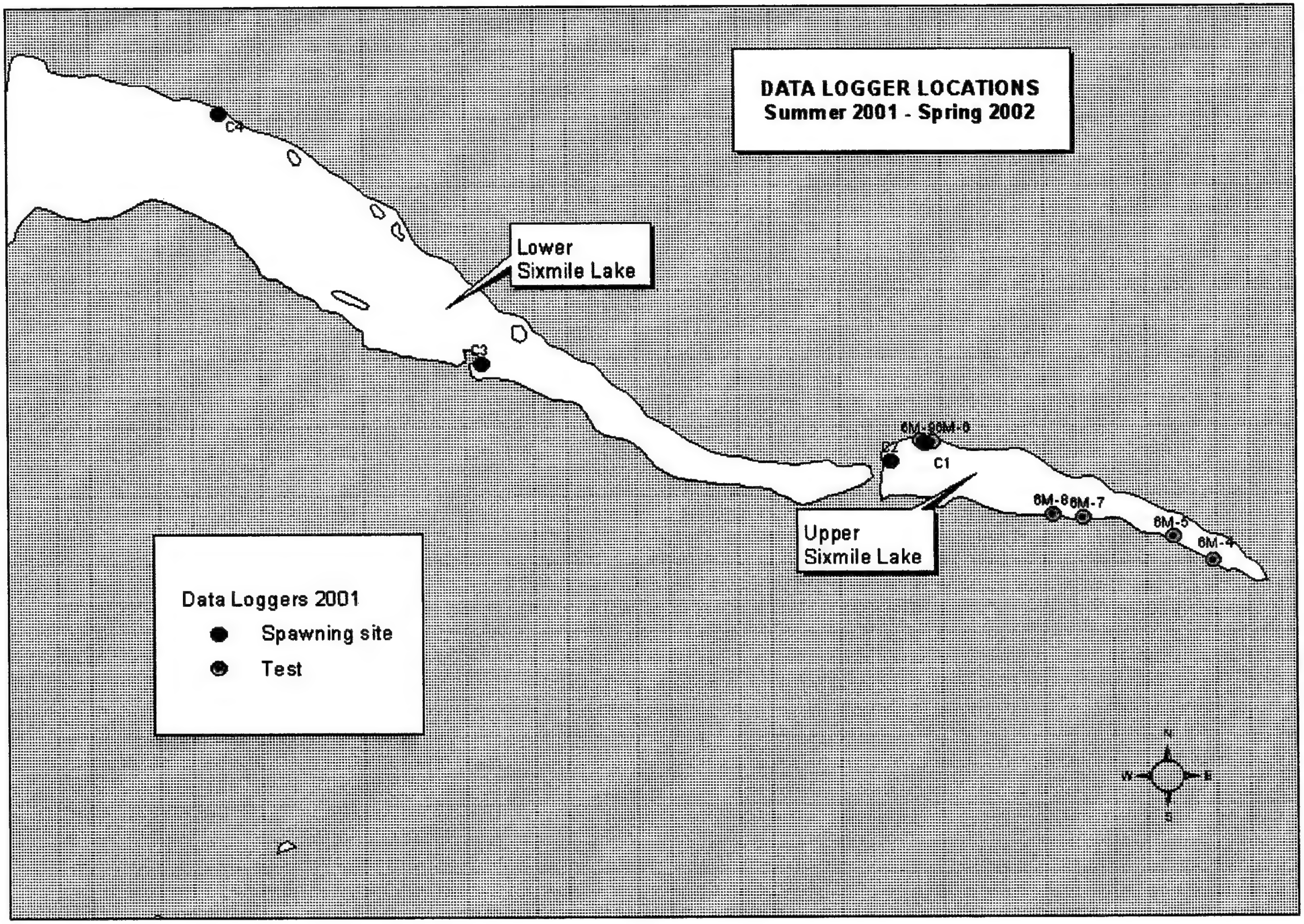

Figure 13. Locations of temperature data loggers in Upper and Lower Sixmile Lakes, Elmendorf AFB, summer 2001 to spring 2002.

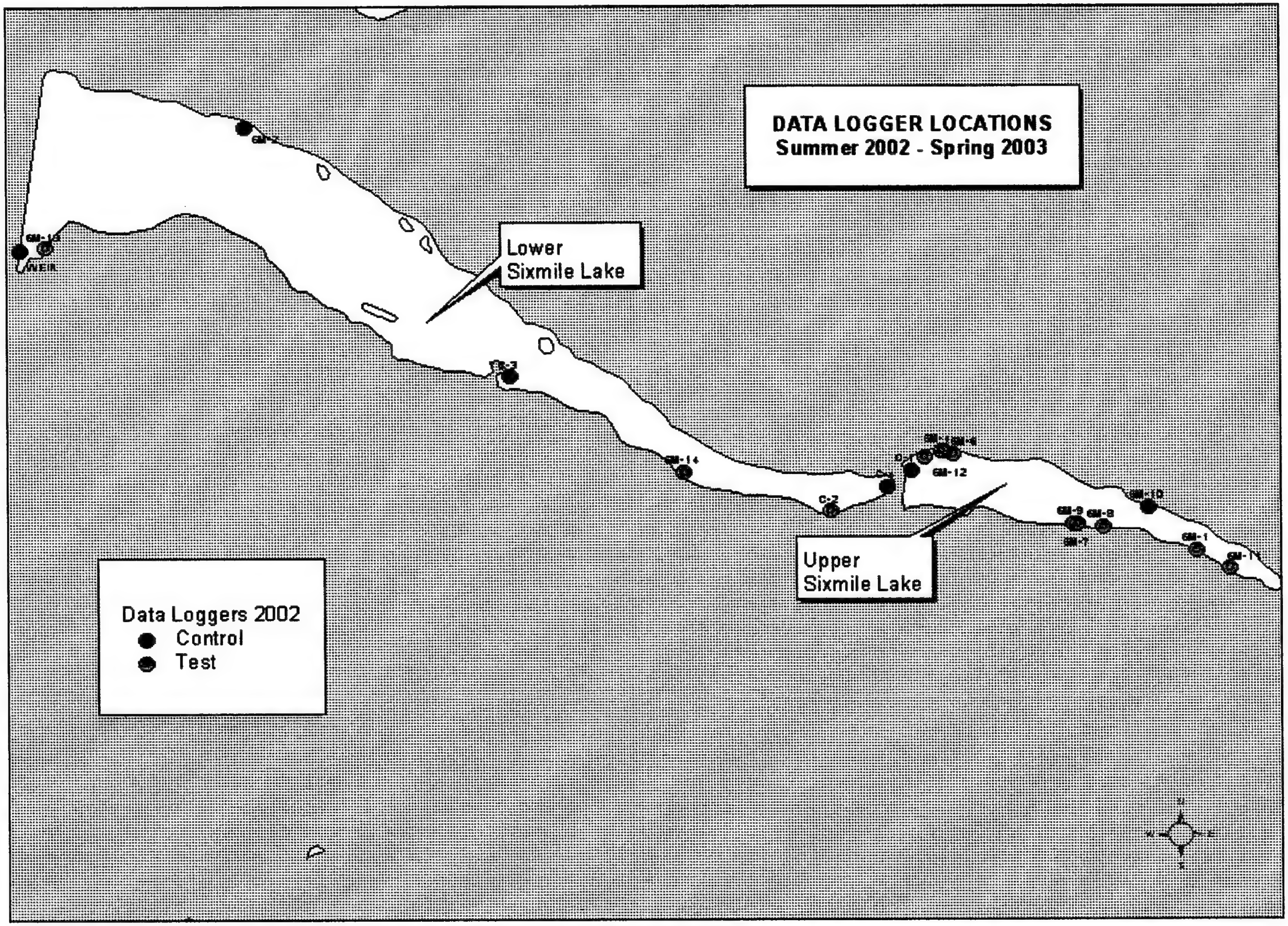

Figure 14. Locations of temperature data loggers in Upper and Lower Sixmile Lakes, Elmendorf AFB, summer 2002 to spring 2003.

Table 2. Data logger water temperature summary for control and spawning sites, 2001.

Control Sites

Data logger ID	C1	C2	C3	C4
Lake	Upper	Upper	Lower	Lower
Mean Temp ©	6.71	6.97	6.64	no data
Standard Error	0.03	0.02	0.05	no data
Median	4.50	5.26	4.92	no data
Mode	3.08	2.89	1.99	no data
Standard Deviation	5.08	4.03	4.72	no data
Sample Variance	25.78	16.28	22.28	no data
Range	37.45	19.98	24.69	no data
Minimum	0.87	2.89	1.69	no data
Maximum	38.32	22.87	26.38	no data
Count	31796	31844	7889	no data

Spawn sites

Data logger ID	6M-3	6M-4	6M-5	6M-6	6M-7	6M-8	6M-9
Lake	Upper	Upper	Upper	Upper	Upper	Upper	Upper
Mean Temp ©	no data	3.27	3.62	3.54	3.36	3.78	4.66
Standard Error	no data	0.10	0.04	0.14	0.05	0.05	0.12
Median	no data	0.83	2.72	0.52	2.67	2.63	1.97
Mode	no data	0.53	2.72	0.22	2.37	2.33	1.37
Standard Deviation	no data	4.06	1.60	5.35	1.86	1.96	4.80
Sample Variance	no data	16.46	2.56	28.61	3.46	3.84	23.03
Range	no data	14.24	7.83	21.07	9.03	8.43	17.20
Minimum	no data	0.23	1.84	-1.58	1.18	2.33	1.07
Maximum	no data	14.47	9.67	19.49	10.21	10.76	18.27
Count	no data	1499	1514	1498	1514	1511	1514

Table 3. Data logger water temperature summary for control and spawning sites, 2002.

Control Sites

Data logger ID	6M-1	6M-10	WEIR	C1	C3	C4
Lake	Upper	Upper	Lower	Upper	Lower	Lower
Mean Temp ©	3.84	4.89	5.45	5.19	no data	no data
Standard Error	0.07	0.12	0.14	0.01	no data	no data
Median	2.54	2.49	3.12	4.34	no data	no data
Mode	2.24	1.31	1.64	3.40	no data	no data
Standard Deviation	2.64	4.48	5.02	2.08	no data	no data
Sample Variance	6.99	20.07	25.24	4.33	no data	no data
Range	21.43	21.42	25.01	10.39	no data	no data
Minimum	0.76	0.72	1.64	3.40	no data	no data
Maximum	22.19	22.14	26.65	13.79	no data	no data
Count	1441	1442	1336	23619	no data	no data

Spawn sites

Data logger ID	6M-2	6M-4	6M-5	6M-6	6M-7	6M-8	6M-9
Lake	Lower	Upper	Upper	Upper	Upper	Upper	Upper
Mean Temp ©	no data	4.29	no data	4.24	3.37	3.16	3.11
Standard Error	no data	0.09	no data	0.10	0.08	0.10	0.05
Median	no data	2.61	no data	2.60	2.37	1.44	2.26
Mode	no data	2.61	no data	2.01	1.48	0.53	1.97
Standard Deviation	no data	3.27	no data	3.44	2.91	3.69	1.75
Sample Variance	no data	10.69	no data	11.85	8.45	13.64	3.07
Range	no data	13.62	no data	15.10	13.40	14.88	8.75
Minimum	no data	2.02	no data	1.42	-0.01	-0.06	1.07
Maximum	no data	15.64	no data	16.52	13.39	14.82	9.82
Count	no data	1439	no data	1303	1303	1305	1305

Table 3 continued. Data logger water temperature summary for control and spawning sites, 2002.

Spawn sites cont'd...

Data logger ID	**6M-11**	**6M-12**	**6M-13**	**6M-14**	**C2**
Lake	Upper	Upper	Lower	Lower	Lower
Mean Temp ©	4.23	4.90	3.98	2.89	3.46
Standard Error	0.04	0.07	0.07	0.02	0.01
Median	3.64	3.96	3.62	2.65	3.06
Mode	3.64	3.96	3.32	2.36	2.58
Standard Deviation	1.36	2.55	2.26	0.81	1.40
Sample Variance	1.86	6.49	5.10	0.66	1.96
Range	8.08	12.12	11.62	6.12	9.05
Minimum	3.34	2.50	1.25	1.47	2.42
Maximum	11.42	14.62	12.87	7.59	11.47
Count	1271	1230	1115	1115	23613

DISCUSSION

Upon preliminary examination, spawning habitat for sockeye salmon in Upper and Lower Sixmile Lakes appears limited because of relatively restricted and patchily distributed gravel substrate, the high degree of aquatic vegetative growth, and the predominantly sand/silt bottom. However, our study showed that the Sixmile Lake system does provide suitable spawning habitat capable of supporting an escapement in excess of 4000 sockeye salmon. Our results provide information on run timing, age class structure, show the types of habitat used by sockeye salmon for spawning and identify some key habitat variables, and provide location information for important spawning areas.

Timing of Spawning

Sockeye salmon generally spawn in late summer and autumn. The timing of spawning appears to be dependent to some degree on the temperature regimen in the gravel where the eggs are incubated and this varies distinctly between spawning area types (Burgner 1991). Sockeye salmon began to pass into Sixmile Lakes two weeks earlier in 2001 (8 July) than 2002 (25 July), yet spawning commenced around 20 August in both years. Peak spawning occurred around 9-16 September and terminated by 9 October during both study years. Additionally, a similar distribution pattern was noted during both years as fish began to enter the lake system. The majority of fishes first entering the lakes schooled up in the deeper, cooler waters at the center of both lakes, or lingered in small schools (25-40 fish) in the old channel bed at the eastern end of Lower Sixmile Lake. Three to six days prior to the commencement of spawning, fish began to move into lakeside spawning areas to establish territories and start digging redds.

Whether or nor sockeye entering the lakes at different times throughout the run utilized different areas for spawning was difficult to determine. We hoped that the results from Peterson disk tagging would provide some answers to this question. Unfortunately, those results were never fully documented due to September 11, 2001 base closures, and tagging was not continued the following year. Based on limited results during 2001 and further observations of untagged fishes during the 2002 spawning season, there was possibly some degree of site selection based on run timing. For example, the first spawning areas occupied during both years were the northwest side of the upper lake and along the western end of the lake against the road and culvert. Next, sites along the southcentral bank of the upper lake, at feeder creek outlets, became populated. Fish tagged with Peterson disks followed this same distribution pattern: fish entering the upper lake first were sighted spawning in the northwest corner; fish that entered the lake the following week established territories at southcentral sites. However, the pattern breaks down after that and tagged fish that entered the system later were found randomly distributed throughout key spawning areas in the upper lake. No fish were observed spawning in Lower Sixmile Lake during 2001. However, during 2002, fish were sighted in the lower lake on 26 August at three sites in low numbers (50-100) and by 4 September they occupied 10 sites (five of which spawning was observed at) in Lower Sixmile. By 4 September, 2002, most sites identified as spawning areas in the upper lake were already occupied. It is possible that spawning habitat in Lower Sixmile Lake is less desirable than habitat in the upper lake, and is therefore occupied after areas in the upper lake are full or near capacity.

Age Composition and Sex Ratio

The age composition of sockeye salmon returning from the ocean to spawn in their natal lakes varies considerable among populations and from year to year within a population (Burgner 1991). During 2001 and 2002, the majority of fish returning to spawn in Sixmile Lakes were either four or five year olds. Four year old fish constituted 62% of the run in 2001 and 42% of the run in 2002, while five year olds made up 39% of the 2001 return and 54% of the 2002 return. Six year olds (age 2.3) were identified during both years, but they comprised only a small fraction of the total run. These results are in agreement with scale samples taken from sockeye out of Sixmile Lake in 1982 when five-year old (2.2) fish dominated the run (based on a sample of 177 fish) (Rothe et al. 1983).

Due to such small sample sizes, we encourage caution if these age ratios are to be used for management purposes. In 2001, 53% (n=79) and in 2002, 61% (n = 252) of scales used for age analysis were illegible because they were either reabsorbed or regenerated. By the time fish enter the Sixmile Lake system they are quite colored and have reabsorbed a large proportion of their scales. Sixmile Creek is near the terminus of Upper Cook Inlet in the Knik Arm, and fish entering the system are in more advanced spawning condition than sockeye seen further south (i.e. Kenai and Susitna Rivers). Scale sampling may not be the preferred sampling technique to use for future studies or a larger sample size may help to statistically overcome the high degree of scale illegibility.

Sampling results revealed the sex ratio of sockeye salmon returning to spawn in the Sixmile system was heavily skewed toward females. Females represented over 70% of the sample during both years of the study. Foerster (1968) noted an excess of females in sex ratio estimates of sockeye approaching the spawning grounds, and suggested that gill nets were quite selective of males exhibiting secondary sexual characteristics. The Sixmile system, as previously mentioned, is at the terminus of Upper Cook Inlet. Fish en-route to Sixmile Lakes pass through numerous gill net fisheries in Cook Inlet before entering the Knik Arm. Furthermore, many of the fish captured at the weir bore net marks, suggesting that they had been previously captured in gill nets but were able to slip through and escape. Interception of males in gillnet fisheries may account, at least in part, for the high percentage of females in our sample. We also suggest that our sample may have been somewhat biased towards females as they were generally easier to capture and fewer escaped during handling.

Spawning Habitat Variables

Sockeye salmon often spawn in the inlet or outlet streams of lakes, and occasionally on gravel beaches along lake shores, allowing vulnerable fry to quickly reach the lake habitat used as rearing areas after emergence from the gravel (Miller and Brannon 1982; Burgner 1991). This study identified spawning habitat within the Upper and Lower Sixmile Lakes, but did not include spawning observations in Sixmile Creek. It is likely that some fish remained in the creek to spawn, although the exact number is unknown. Spawning surveys were conducted on both Upper and Lower Sixmile Lakes during 2001 and 2002. During 2001, spawning activity was observed only in the upper lake. In 2002, spawning was observed in both lakes, although the majority of spawning occurred in the upper lake. Fishes were observed schooling in the lower lake in 2001, and it is likely that they spawned there as well, but this behavior was never documented. During 2002, lower lake sites were occupied later than upper lake sites. It may be

possible that in 2001, lower lake sites were not occupied until after the September 11 base closure, and thus, not recorded. Despite ample gravel spawning substrate in the lower lake, only a small percentage of the available area was utilized by spawning fishes in 2002.

Foerster (1968) found the most suitable bottom characteristic for spawning habitat utilized by sockeye salmon to be medium to small sized gravel with a limited amount of coarse sand, through which a good flow of water could be maintained. During both 2001 and 2002, sockeye salmon spawned most frequently in areas where gravel was small to intermediate in size. This included lakeside gravel beaches, primarily in Upper Sixmile Lake along the northwest shore and adjacent to the roadside and culvert. More than half the spawning salmon documented in this study were located within these two areas. Other areas with gravel substrate were also utilized by spawning fishes. These areas, primarily found along the southcentral shore of Upper Sixmile Lake, were comprised of larger gravel and small rocks that were patchily distributed within small indentations fed by freshwater seeps or feeder creeks.

Several salmonid species demonstrate preferences for sites where up-welling of deep groundwater occurs (Lorenz and Eiler 1989; Hoopes 1972). Spring-fed ponds and side channels also tend to be heavily utilized by sockeye salmon (Burgner 1991; Foerster 1968). Upwelling groundwater and spring-fed ponds provide a significant source of dissolved oxygen and increased circulation through the nest (redd). A study conducted at Lake Nerka and Little Togiak Lake in the Wood River system in Bristol Bay reported that beaches without upwelling groundwater were not used by spawning sockeye, and in those beaches where upwelling occurred, spawning was the heaviest in the areas of strongest upwelling (Burgner 1991). In both Upper and Lower Sixmile Lakes, fish spawned at sites with upwelling groundwater and/or sites that were spring fed. Spawning occurred at the outlets of 21 (of 30) feeder creeks. At the base of feeder creeks, particularly on the southern shore of Upper Sixmile Lake, small gravel patches were the predominant bottom substrate, yet the area surrounding these patches was typically organic material. It is likely that input of water from the feeder creeks was able to create sufficient circulation to clear away organic material in the near vicinity to reveal underlying substrate material.

There appears to be an area of up-welling cold groundwater along the northwest shore of Upper Sixmile Lake, in the area where the highest density of spawning activity was recorded. Average temperatures recorded from four data loggers at these sites ranged from 3.54°C to 4.66°C (2001 and 2002, respectively) compared to mean temperatures of 5.19°C (in 2002) and 6.97°C (in 2001) recorded at adjacent control sites positioned approximately 85m away. Water temperature may also be a factor in habitat selection by spawning salmon (Chambers et al. 1955). Water temperatures recorded at spawning sites were significantly colder than control sites for both years of the study combined. Our data show that the coldest mean water temperatures occurred at the feeder creek outlets.

Vegetative cover also appeared to be a factor in selection of spawning habitat by sockeye salmon. Favored sites were near deeply undercut banks, banks overhung with grass and herbaceous plants, holes washed under tree roots, and deep pools. Such areas provide increased protection from predators (Hoopes 1972). For example, spawning densities were highest within 1 m of shore, beneath the cut bank, along the northwestern shore of Upper Sixmile, in water less

than 1 m. However, as you round the corner to the western end of the lake against the roadside, there is very little vegetative coverage. In this area, fish moved out into deeper water (approx. 2 m) to spawn. Spawning fishes were sighted in deep holes scoured under tree roots and in deep pools (approx. 2 m deep) along the southcentral bank of Upper Sixmile and at the southeastern end of the lower lake. We did note evidence of predation by bears at many of the bank undercut spawning sites along the southern shore of Upper Sixmile Lake.

Water depth did not appear to be a decisive factor in the selection of spawning sites for fishes in the Sixmile system. At some of the feeder creek outlets, spawning was observed while fish's dorsal surfaces protruded above the water. In the Bristol Bay area, spawning along lake beaches is commonly at depths of less than 3-4 m (Burgner 1991). In this study, spawning was not observed in water deeper than 2 m, although there were places in both lakes deeper than this. Due to the fact that the majority of fishes known to occur in the lakes were accounted for during spawning surveys, and that most spawning habitat identified through visual observation and habitat modeling was in water 2 m or less, we feel reasonably certain we recorded the majority of spawning activity, and this occurred in nearshore, shallow areas.

Important Spawning Areas

It was necessary to define and determine what constituted spawning habitat for sockeye salmon in Sixmile Lake in order to successfully identify "key" spawning areas. In this study, we defined spawning habitat as only those areas where spawning was actually observed, allowing the fish to define habitat suitability. During 2001 and 2002, we documented at least 18 (and as many as 22) key spawning sites within a limited range of habitats – 13 (to 17) in the upper lake and five in the lower lake. High density habitats included areas with small to medium gravel as the bottom substrate and areas of upwelling groundwater. Habitats utilized to a lesser degree, or where spawning densities were lower based on limited or patchy habitat included feeder creek outlets (those with gravel bottoms and/or detrital bottoms), areas with a high degree of vegetative coverage, and in deep pools and under logs. Conditions in Upper Sixmile Lake appeared to be more suitable for spawning salmon than in the lower lake. We speculate this is due to the lack of freshwater input in the lower lake, as 30 feeder creeks were documented in the upper lake and only two in the lower lake, and spawning densities in the lower lake were highest at both feeder creek outlet sites.

The amount of habitat available at the time of spawning can limit the number of eggs successfully deposited on the gravel, setting an upper limit on the size of the next generation and potentially acting as a density-dependent regulator of population size when density of the spawning population is very high (McNeil 1964; Allen 1969; McFadden 1969; Reeves et al. 1989). Based solely on observation, the spawning habitat in Upper and Lower Sixmile Lakes did not appear to be limited. Although spawning densities were high in priority sites, there were an ample number of secondary sites that were used for spawning once primary sites were full. Additionally, there were a number of gravel sites in the lower lake where potentially suitable substrate was available, yet remained unused.

KEY RESEARCH ACCOMPLISHMENTS

- Identified 18 to 22 key spawning areas in Upper and Lower Sixmile Lakes and created maps representing these areas. Also identified important habitat variables utilized in selection of spawning habitat by fishes.
- Developed ArcView GIS database identifying sockeye salmon spawning sites and provided physical layers such as modeled coverages of bottom type and bathymetry. Database is dynamic and queryable. Spawning and other biological information may be continuously added to it for future management use.
- Located and mapped feeder creek sites, during summer and winter.
- Provided record of water temperature conditions at spawning locations and at control sites.
- Randomly sampled returning adult salmon population to assess age class and sex ratios

REPORTABLE OUTCOMES

No reportable outcomes have resulted from this research to date.

CONCLUSIONS

Sockeye salmon returning to spawn in the Sixmile Lake system were primarily four and five year old fish. During 2001 and 2002, the spawning period ranged from 20 August to 9 October, with peak spawning occurring during the second to third weeks in September. At least eighteen key spawning sites were identified in Upper and Lower Sixmile Lakes. Sockeye utilized the same areas in the upper lake in 2001 as they did in 2002. Spawning was not documented in Lower Sixmile Lake in 2001, but it was observed there in 2002. It is likely spawning was missed in Lower Sixmile Lake during 2001 due to base closures after the September 11 terrorist attacks. The majority of spawning was observed in the upper lake along the northwest bank and against the roadside/culvert area. Primary spawning habitat consisted of small to medium gravel and areas of upwelling groundwater and or feeder creek input where water temperatures were substantially lower than throughout the rest of the lake. Secondary spawning sites included areas with larger gravel, ample vegetative coverage, under cutbanks and fallen logs, and in deep holes. Overall, there appears to be sufficient, albeit patchily distributed, spawning habitat in the Sixmile Lakes to maintain a salmon population of approximately 4000 sockeye salmon. Should escapement exceed 4000 fishes and priority upper lake spawning sites become full, there appears to be ample additional spawning substrate in the lower lake, although most of these areas are deeper than 2m. Whether or not additional lower lake sites have sufficient flow regimes from upwelling groundwater is unknown.

MANAGEMENT IMPLICATIONS

Sockeye spawning habitat in the Sixmile Lakes does not appear to be a limited. At this time, the Sixmile sockeye run is self-sustaining, and requires little management interference. Continued monitoring of escapement into the lakes is recommended. Should escapement exceed 5000

fishes, we encourage increasing sport fish catch limits and/or gear allowances (i.e. allow for snagging) as to avoid overescapement. The third year of this study, which assesses the health of the outmigrating smolt and lake conditions, in combination with the results from the spawning habitat study, should provide insights into the competitive fitness of juvenile fishes and may help to identify escapement thresholds.

Spawning fishes showed preferences for areas with small to medium gravel, hence, the majority of spawning occurred against the roadway and just northwest of the culvert. Some of this area is currently closed to fishing and we suggest extending the area to encompass the entire west end of Upper Sixmile Lake and the northwest bank. Fishermen are currently allowed to fish the northwest corner of the lake and have been observed standing in the water along the lake edge. Restricting access to this would reduce stressors to spawning fishes and insure that trampling of incubating eggs does not occur. Additionally, boaters should be discouraged from entering areas where large numbers of fishes are spawning.

Freshwater input from feeder creeks along the southern bank of both lakes appears to be an important factor in spawning habitat selection by sockeye. Although highly unlikely that it would occur, we discourage any type of development along the southern shore that would interfere with freshwater drainage into the lakes.

LITERATURE CITED

Allen, K.R. 1969. Limitations on the protection of salmonid populations in streams. Pages 3-20 In: T.G. Northcote (ed.). Salmon and trout in streams. H. R. MacMillan lectures in fisheries. Univ. British Columbia. Vancouver.

Burgner, R.L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). Pages 1-118 In: C. Groot and L. Margolis (eds.). Pacific salmon life histories. University of British Columbia Press. Vancouver, B.C.

Chambers, J.S, G.H. Allen, and R.T. Pressey. 1955. Research relating to the study of spawning gravels in natural areas. Annual Report 1955. Wash. Dept. Fisheries Olympia.

Foerster, R.E. 1968. Sockeye spawning grounds and spawning success. Chapter 6 In: The sockeye salmon, *Oncorhynchus nerka.* Fisheries Research Board of Canada, Bulletin 162. Ontario, Canada.

Hoopes, D.T. 1972. Selection of spawning sites by sockeye salmon in small streams. Fishery bulletin 70:447-458.

Lorenz, J.M. and J.H. Eiler. 1989. Spawning habitat and redd characteristics of sockeye salmon in the glacial Taku River, British Columbia and Alaska. Transactions of the American Fisheries Society 118:495-502.

McFadden, J.T. 1969. Dynamics and regulation of salmonid populations in stream. Pages 313-328 In: T.G. Northcote (ed.). Symposium on salmon and trout in streams. Univ. British Columbia. Vancouver, B.C.

McNeil, W.J. 1964. Redd superimposition and egg capacity of pink salmon spawning beds. Journal Fisheries Research Board Canada 21:1385-1396.

Miller, R.J. and E.L. Brannon. 1982. The origin and development of life history patterns in Pacific salmonids. Pages 296-309 In: E.L. Brannon and E.O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. Univ. Wash. Seattle.

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. USDA Forest Service Gen, Tech. Rpt. PNW-GTR-245. Pacific Northwest Research Station. Portland.

Rothe, T.C., S.H. Lanigan, P.A. Martin, and G.F. Tande. 11983. Natural resource inventory of Elmendorf Air Force Base, Alaska: Part I. U.S. Fish and Wildlife Service Technical Report. Prepared for 21st Combat Support Group/DEEV, Elmendorf Air Force Base. 368 pps. plus appendices.

Schuett-Hames, D., A. Pleus. 1996. Literature review and monitoring recommendations for salmonid spawning habitat availability. Northwest Indian Fisheries Commission. Report No. TFW-AM-9-96-002. 19 pp.

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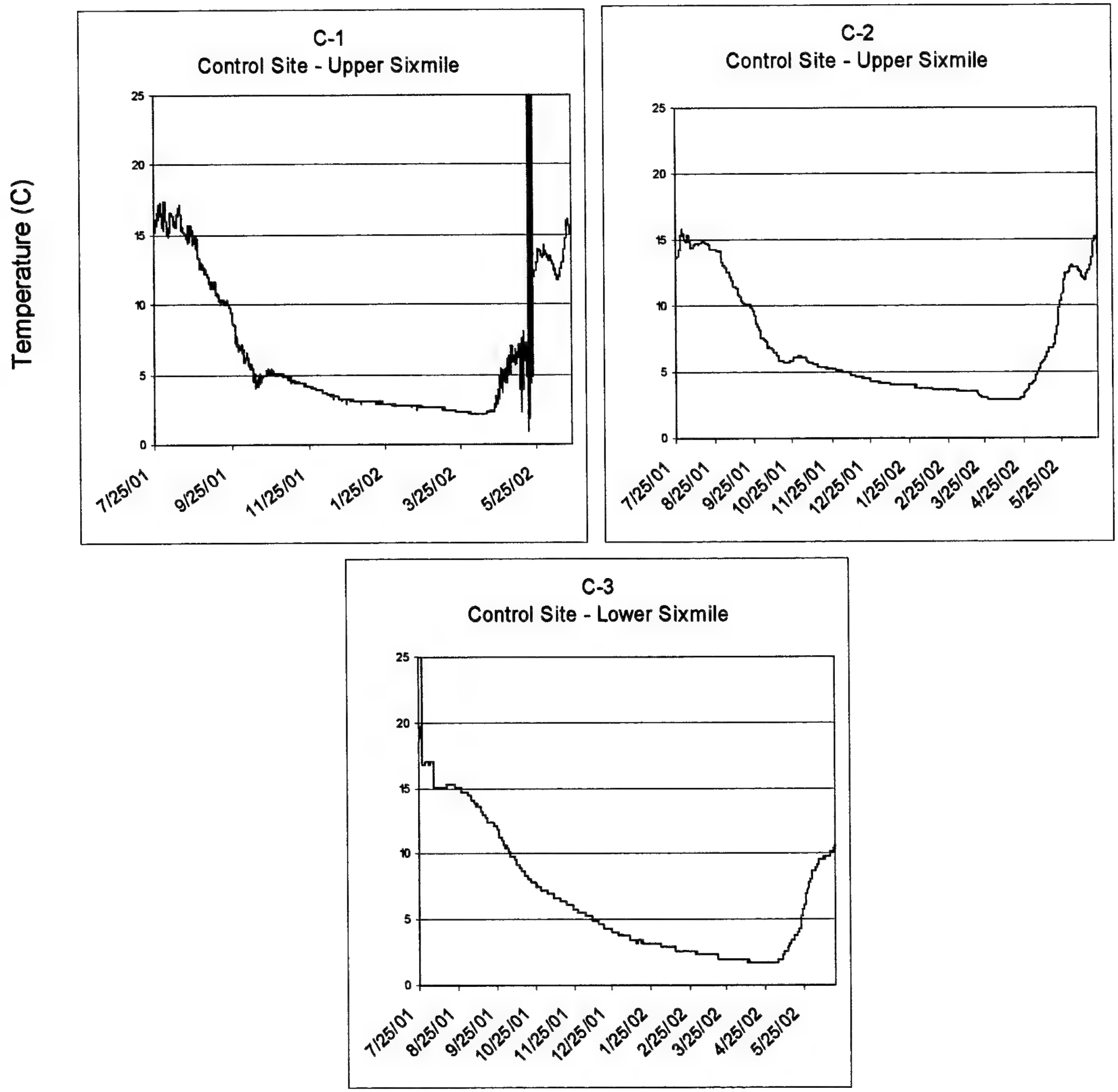
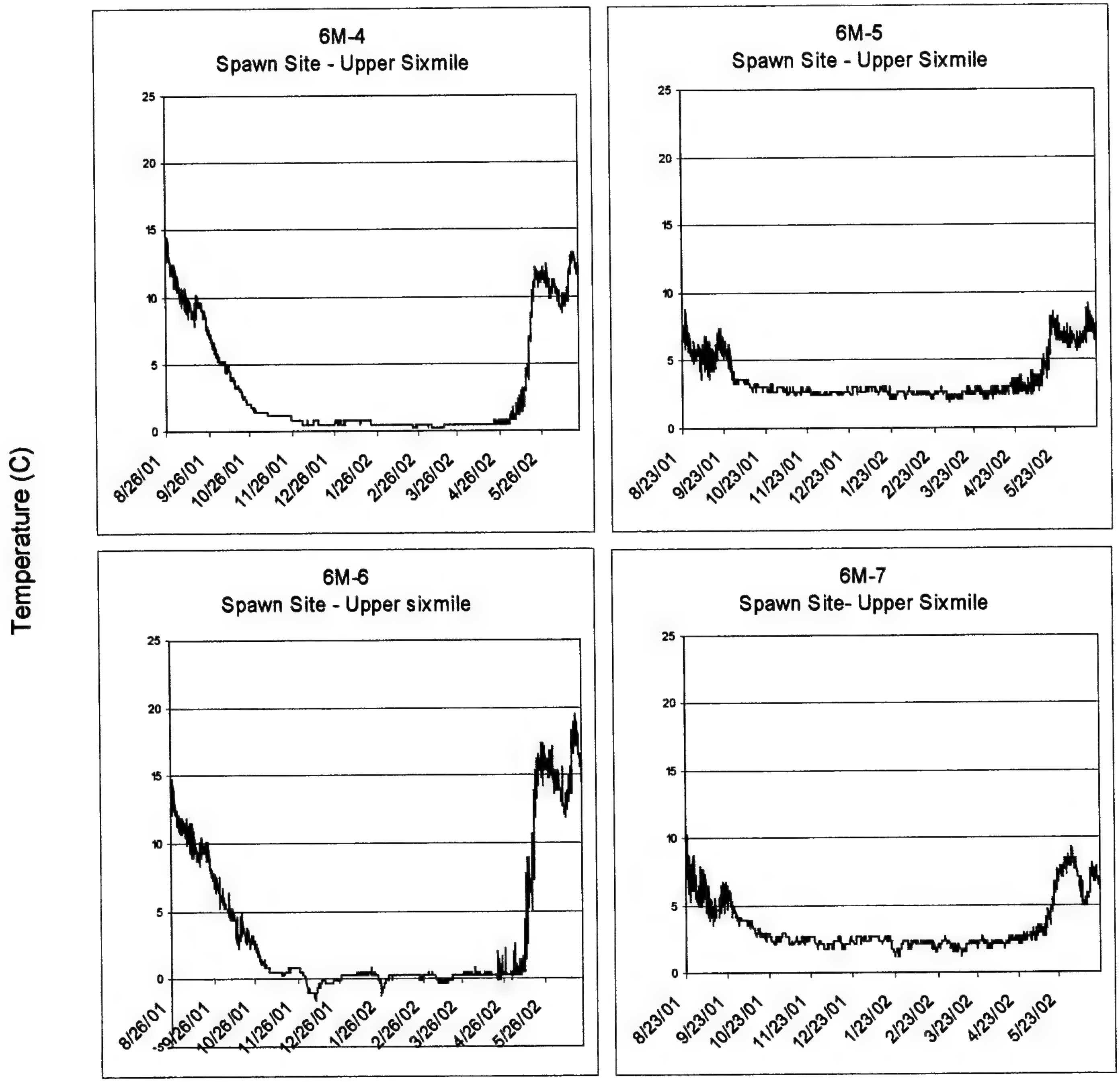
APPENDIX I

Temperature Data Logger Summary

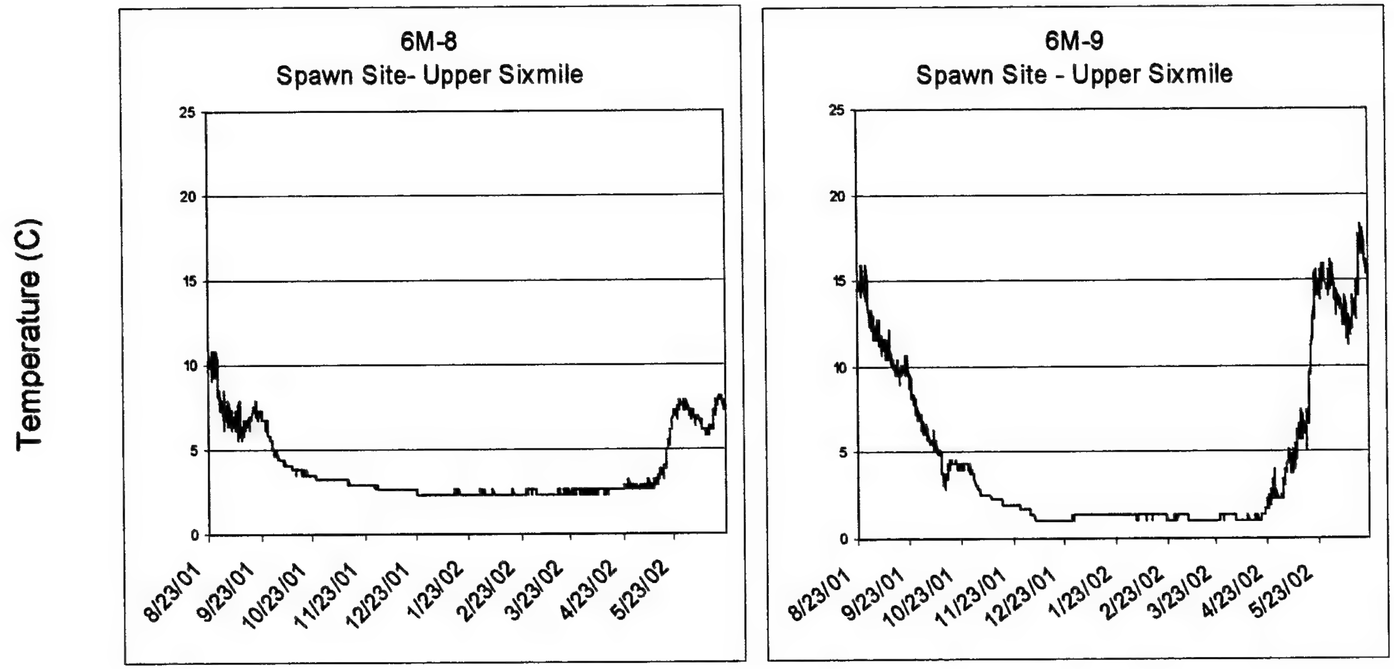
Data logger water temperature summary graphs for control and spawning sites in Sixmile Lakes, fall 2001to spring 2002.



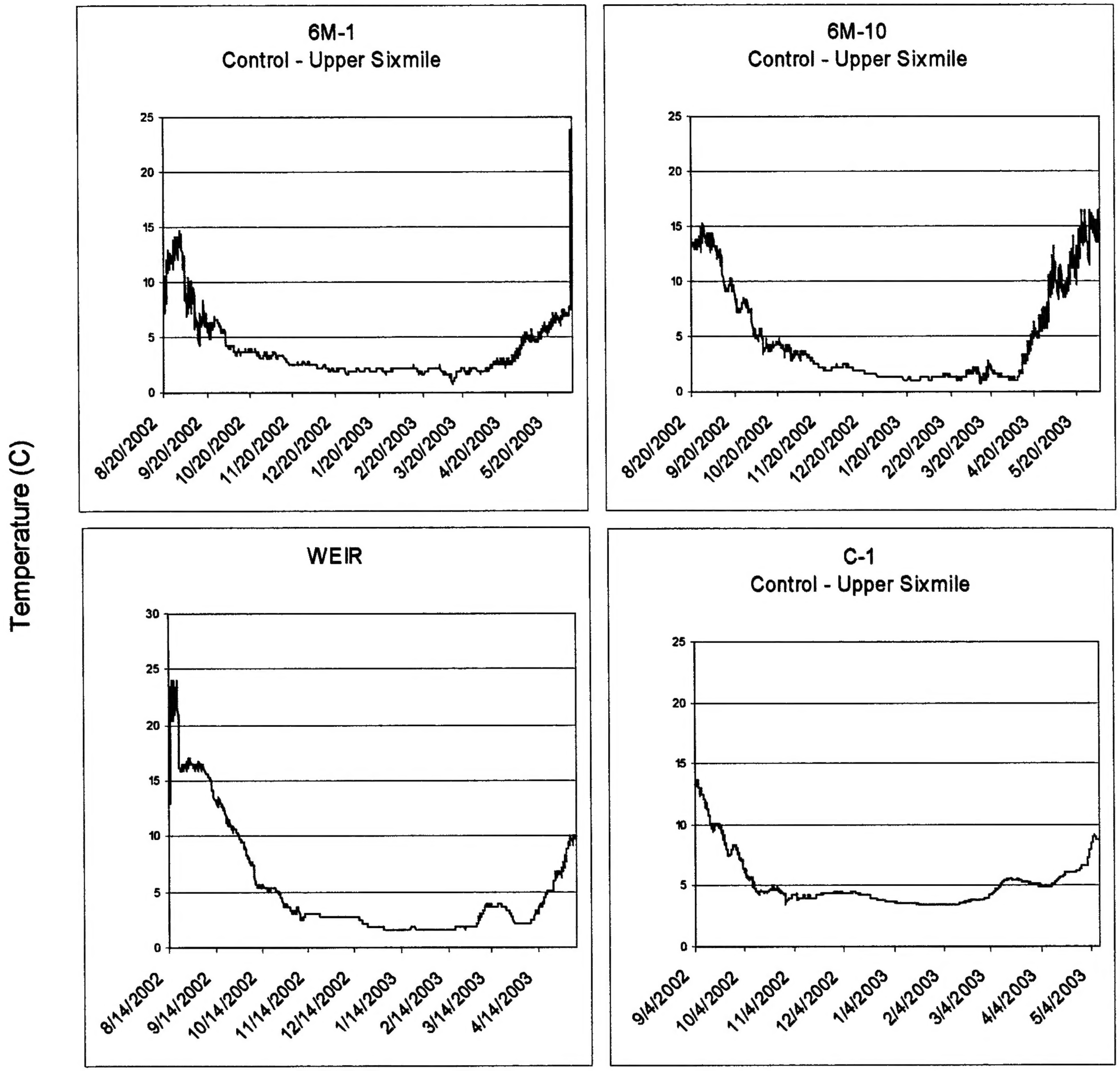
Data logger water temperature summary graphs for control and spawning sites in Sixmile Lakes, fall 2001to spring 2002.



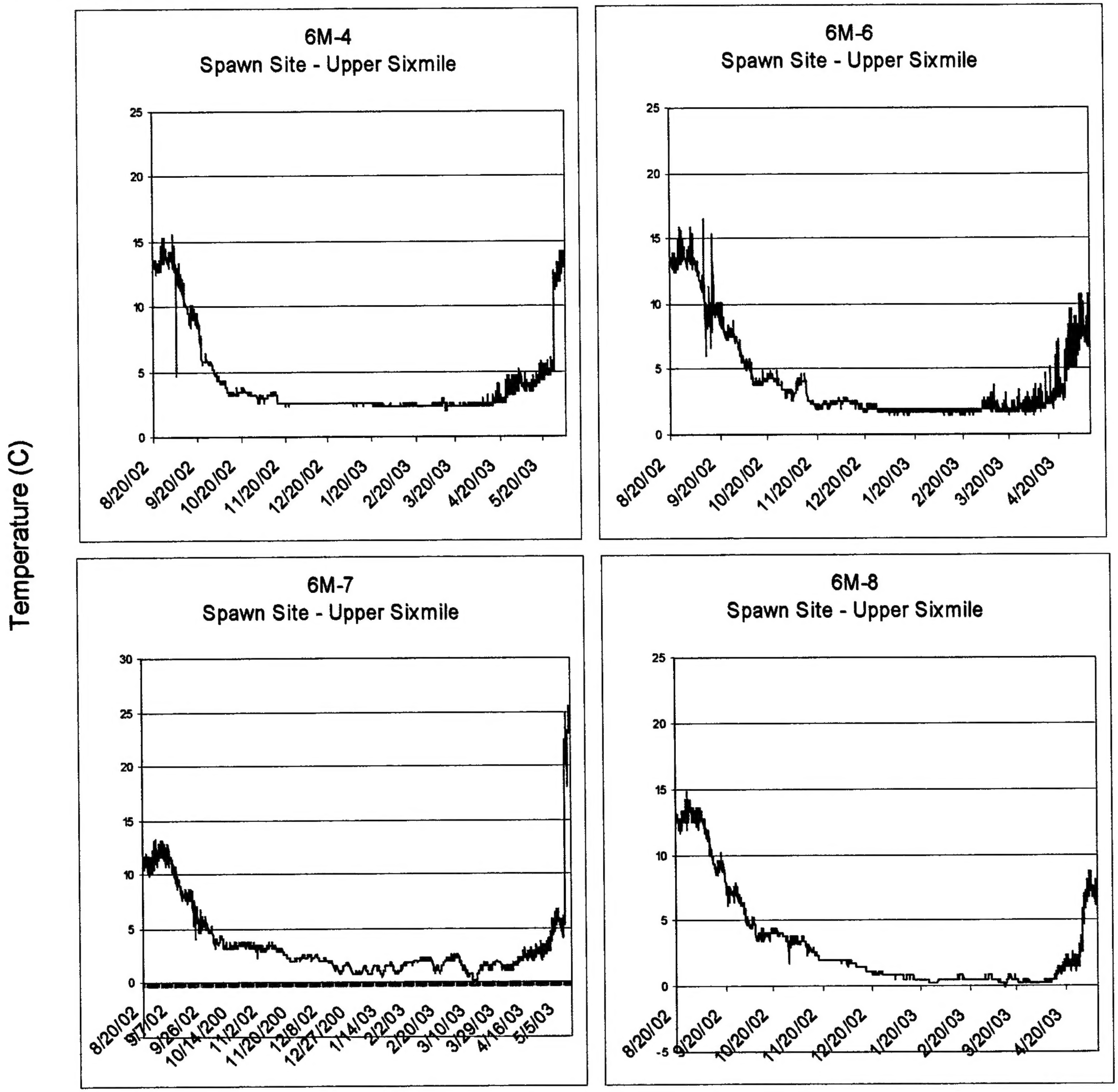
Data logger water temperature summary graphs for control and spawning sites in Sixmile Lakes, fall 2001to spring 2002.



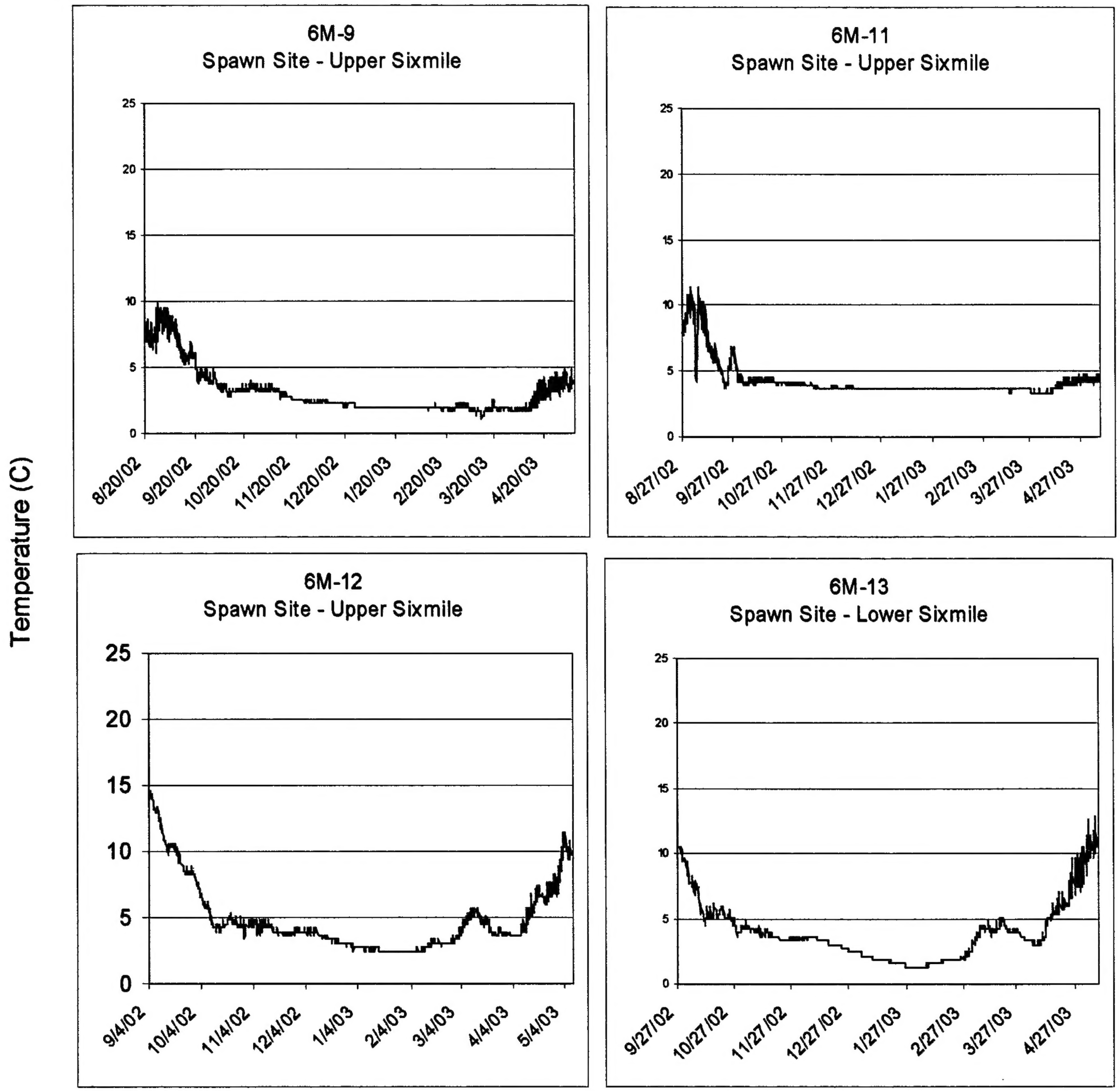
Data logger water temperature summary graphs for control and spawning sites in Sixmile Lakes, fall 2002 to spring 2003.



Data logger water temperature summary graphs for control and spawning sites in Sixmile Lakes, fall 2002 to spring 2003.



Data logger water temperature summary graphs for control and spawning sites in Sixmile Lakes, fall 2002 to spring 2003.



Data logger water temperature summary graphs for control and spawning sites in Sixmile Lakes, fall 2002 to spring 2003.